TOOLS FOR MACHINISTS AND WOODWORKERS

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TOOLS FOR

ENGINEERS AND WOODWORKERS

TOOLS

FOR

MACHINISTS AND WOODWORKERS

INCLUDING

MODERN INSTRUMENTS OF MEASUREMENT.

A PRACTICAL TREATISE COMPRISING A GENERAL DESCRIPTION AND CLASSIFICATION OF CUTTING TOOLS AND TOOL ANGLES, ALLIED CUTTING TOOLS FOR MACHINISTS AND WOODWORKERS; SHEARING TOOLS; SCRAPING TOOLS; SAWS; MILLING CUTTERS; DRILLING AND BORING TOOLS; TAPS AND DIES; PUNCHES AND HAMMERS; AND THE HARDENING, TEMPERING AND GRINDING OF THESE TOOLS. TOOLS FOR MEASURING AND TESTING WORK, INCLUDING STANDARDS OF MEASUREMENT; SURFACE PLATES; LEVELS; SURFACE GAUGES; DIVIDERS; CALIPERS; VERNIERS; MICROMETERS; SNAP, CYLINDRICAL, AND LIMIT GAUGES; SCREW THREAD, WIRE AND REFERENCE GAUGES; INDICATORS, TEMPLETS, ETC., ETC.

BY

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PREFACE.

THE object of this book is to give an account of such Tools as are commonly used by Engineers and Wood-workers, written chiefly from the standpoint of the men who have to use them, and who desire to understand the principles which underlie the forms in which those Tools are found. Practical instructions for their employment, as suggested by the writer's own experience, have been added. The work (it is believed) is more comprehensive in its scope than any which has preceded it, the subject of Instruments of Measurement being treated in a very full manner and freely illustrated (as are all sections of the work) with drawings of leading types.

Although, in strictness, Tools and Measuring Instruments form distinct groups, they cannot be separately regarded in shop practice, since modern methods of measurement are directly related to certain systems of manufacture, both general and special in character. The subjects treated here have never previously assumed such great importance as in recent years. Tool-making has been developed into highly specialised branches of manufacture, different firms taking up different classes or groups of Tools and Instruments, with the perfection of results and fine precision that come of specialisation. Some of

these results will be found here illustrated in book-form for the first time.

The great and growing importance of Cutting Tools in modern practice is evidenced by the numerous experiments to which they have been subjected. But the experience of the shops still remains of highest value, and only in very general terms can these experiments be applied as yet to practical issues. As they relate to Lathe Tools chiefly, some account of them will be found in another work (now in the press) by the same Author, dealing with "Engineers' Turning."

It should be mentioned that a large part of the matter included in this volume consists of selections from various articles contributed by the Author to the *English Mechanic* and the *Mechanical World*, which have been carefully revised and supplemented where necessary, but several chapters are chiefly or entirely new, and a substantial proportion of the illustrations given have been specially drawn and engraved for the work.

JOSEPH HORNER.

BATH, *November* 1904.

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TOOLS FOR ENGINEERS AND WOODWORKERS.

INTRODUCTION.

A General Survey of Tools.

The Term Tool Defined—Distinction between a Tool and a Machine—and an Appliance—Instruments for Measurement and Test—Broad Grouping—Machine-operated Tools, and Modern Manufacture—Percussive Tools—Moulding Tools—Interchangeable System—The New Steels.

IT is necessary to have a clear definition of the meaning of the word tool. What is a tool? in what respect is it distinguished from a machine, an appliance, an implement, or an instrument? The term is used in a very loose fashion, but the scope of this volume must be restricted to the legitimate meaning of the word.

On first thoughts, it might seem as though the dictionary definition were correct—being any instrument of manual operation, one dependent for its effect on the strength and skill of the operator. But, though that would hold good in a primary sense, and absolutely so, say about a hundred years ago, it does not by any means cover the legitimate meaning of the term to-day. Such a definition would exclude all the vast numbers of tools which are held in and operated by machines, all of which are directly related to, or derived from hand tools, and, in some cases, are similar to, or identical with the latter.

The machines themselves, however, do not come under the classification of tools, though this term is commonly and loosely applied to them, and also, and more correctly, the phrase machine-tools. These therefore will not receive any treatment in this volume.

The distinction between a tool and an appliance is also to be borne in mind. Anything by which the progress of work is facilitated we call an appliance, or in some forms, a templet, or a jig, the three terms denoting different objects. Just where to draw the line here is difficult. A spanner is a tool, but though a vice may be considered as a tool, it is strictly an appliance, since it holds, but does not operate on work. In these and kindred matters, the limitations of a volume must be borne in mind in making selection, and so only those articles which can be legitimately classed as tools will receive treatment.

There is another large group of tools which are also termed instruments, being those employed for marking out, and in the measurement and testing of work. They are tools, because employed in and being essential to the conduct of manual operations. The growth of, and the increased importance of these in recent years has been of a phenomenal character, and no treatise on tools from which these are to be omitted can now be considered as in any sense complete.

Having defined the sense in which we propose to regard tools, let us now see how the subject most naturally divides itself.

First we have the two broad groups—of tools; and of instruments for measurement. The first includes a large number which we can classify broadly as follows, notwithstanding that overlapping occurs in some of the groups.

Tools which act by cutting, by shearing, by scraping, by abrasion, by detrusion, by percussion, tools which operate by moulding on plastic, or on loose materials, and those of the lever class. And in connection with all except the last two, there is the question of the maintenance of maximum efficiency, by hardening, tempering, and grinding.

Under the head of instruments of measurement are included tools used for marking lines, straight and circular, on work, for obtaining the geometrical relations of such lines, and for producing centres. These constitute several large groups. Another great class which includes several groups is employed for checking and testing the accuracy of work in progress and when completed. And these again include two important subdivisions—those which are employed for direct measurement, and those for measurement by the sense of touch or contact, *e.g.*, rules, and gauges.

Overlapping occurs in these groups, as in many cutting,

shearing, and abrasive tools, in detrusive and shearing tools, and in those used for measurement and test by contact, combined with direct measurement.

Tools of the lever class include spanners and clamps, pincers and pipe wrenches, tap wrenches, screwdrivers, and allied forms.

Percussive tools form a very large group, for almost every trade has its own distinct group of hammers. Besides there are the hammers incorporated with machines.

Moulding tools are used by plasterers, modellers, and iron and brass founders, and these are large groups.

There is also the distinctly modern aspect of the study of tools, which must be indicated, because it looms so large in the practice of present-day engineering. The substitution of the machine-operated tool for the hand tool has been followed and supplemented and modified extensively by a system of manufacture known as the Interchangeable. The essential difference between this system and the older one is, that all similar pieces will interchange in the first, and that they will not in the second. That is, if a thousand pieces were thrown in a heap, any one picked up at random would fit at once in its position in any one of a thousand mechanisms of which it forms a part. Little knowledge of machine work is required to understand that perfect interchangeability demands a very fine adherence to fixed dimensions. A variation of only a few thousandths of an inch makes all the difference between too close a fit and one too loose. Such fine dimensions are worked to in hand operations by a tedious process of fitting, of mutual adjustments, of trial and error. In this way perfect fitting of parts can be effected. But the important point is this, that much more than a close mutual fitting of parts is required if pieces are to interchange. They must all be to exact and absolute dimensions, which is quite another condition. There is almost an infinite difference between the mutual fitting of a few parts and of, say, a thousand similar pieces, the cost of which would be excessive if done by hand-operated tools. The difference is that between shaping pieces to exact gauged dimensions in machines, and their correction by the manual skill of the fitter after the work of the machines has been completed. Then the parts are mutually fitted only, but not to dimensions predetermined to some minute fractional parts of an inch or millimetre.

The difference is most important from the point of view of shop economies and of competitive manufacture. To put the case in a concrete fashion, suppose that small arms, sewing machines, and typewriting machines were each finished by the manual skill of the fitter, instead of being put together or "assembled," as the parts come from the machines. The cost would not only be enhanced enormously, but whenever a part should require renewal, the entire mechanism, or a considerable portion of it, would have to be sent back to the factory to be refitted.

It was in France first of all, in the manufacture of muskets, but subsequently in America, that the interchangeable system received its early development. Machines and accessories, jigs, templets, and special tools were designed at great cost, and with much labour, to ensure absolute uniformity in the dimensions of similar parts independently of the skilled craftsman, and with corresponding economy of labour and reduction in the cost of manufacture. Milling machines, screw machines, and the turret lathe were early employed in this work. The system reached its highest development in the United States, and from thence was imported to England, being applied at first to the manufacture of small arms. But the Americans subsequently adapted the system to the production of sewing machines, of watches, and numbers of small articles, and then lastly into the work of machine tool making. Many engineering firms in England and Germany have adapted their shop systems to the production of strictly interchangeable parts. It requires little prescience to see that on the extent to which this system is adopted, the vitality and permanence of many competitive firms will depend.

There is an immense difference in machine manufacture carried on under such a system and the older one. In the latter, each machine is the product of high manual skill, made to order and singly, each part being produced and carried singly through all the departments, and subjected in the process of putting together to innumerable corrections at the hands of the skilled mechanic. No dimensions are gauged precisely, but corrected to fit "full" or "bare," as required for mutual fitting.

In the new system, machines are produced, not by the labour of highly skilled, highly paid mechanics, but either by unskilled cheap labour or by skill of a low grade. Such close accuracy in

absolute dimensions, produced in parts in large quantities at a low cost, are apparently antagonistic conditions. They are not so in fact in modern practice. They are obtained with ease, and with variations so slight that fine gauges are required to detect them. Parts are made an "easy fit," a "tight fit," a "driving fit," as desired, and, out of thousands, the percentage of misfits is very small. The difference between the old and the new, the heterogeneous and the uniform, the mutual fitting by skilled labour, and the absolute fitting to gauge, is wholly a question of machinery of an automatic or semi-automatic character. The broad contrast between these machines and methods and those which they displace is this: The provisions for cutting to the required dimensions are embodied in the machines themselves, while in the older system accuracy depends on the care exercised by the attendant in checking the size of work while in progress. The movements of modern machines are not arrested until the work is finished, and the product is then removed without measuring it at the machine. The main difference is therefore that due to the substitution of automatic and semi-automatic action and control for that of the workman.

Another, the latest development in tools, relates to the material employed, the "high speed steels," by which output is trebled or quadrupled. These steels date from 1900, when the Taylor-White brand was exhibited at Paris. Many other brands are now in the market, and the remarkable result is that lathes are being re-designed to endure the stresses imposed by the new cutting steels, which are often capable of removing over a ton of cuttings in a day of nine hours.

CHAPTER I.

Tool Angles.

Knives and Razors—The Chisel Group—Planes—Chisels for Metal—Principles Underlying Tool Angles—Tool Formation—A Compromise—Lessons from the Chisel—Angles Controlled by Characteristics of Materials—Shavings and Chips—Action of the Plane Compared with Metal Cutting Tools—Lessons Learned from Hand Tools—Rigidity of Tools—Summary of Practical Results—No Hard and Fast Rules—The Importance of Support Afforded to the Work and the Tools—and of Lubrication—Tools that Embody the Chisel Action—The Scrape—Abrasion—Shearing—Detrusion—Tools which Occupy an Uncertain Position.

WE will now endeavour to trace rapidly the tool angle principle through many diverse forms, ranging from the keenest cutting tools to those which operate by scraping only.

The principle on which the forms of cutting tools are based is traceable through many, and on first thoughts unrelated, types. Tools of the chisel form will cut anything from cork and leather to the tough and hard steels. The saw will sever wood, stone, brass, iron, and steel. The differences are simply different applications of the fundamental principles on which the tools are made.

The keenest tools are the knife and razor, in which the cutting angles measure a few degrees only, seldom or never exceeding 20°. These are not required to sever or shave hard substances, and they therefore retain their edge for a reasonably long period.

The next increase in angle occurs in the chisels and cognate forms for cutting soft and hard woods. The grinding angle here is increased to from about 20° to 25°, and we have our first examples of a sharpening facet, the angle of which with the permanent face is slightly greater than the grinding angle. This, however, is only a matter of convenience, because less time is occupied in sharpening such a narrow facet, than would be required for sharpening all over the ground bevel.

Akin to the chisels in degree of angle, and in method of sharpening just noted are the gouges, draw-knife, hatchet, axe, adze, turning chisels, and gouges, carvers' tools, and allied forms. A feature which all these have in common is, that no coercion is exercised upon them, save that of the workman's hands. They can lay when in action flat against the work, or be tilted, and thrust, or driven to suit the shape of the surface of the piece operated on, and the object which the workman has in view. The chief distinction between the tools of this group is that of operation by thrust, as in the true chisels and gouges, and that by percussion, as in the hatchet, and adze group. Here, however, overlapping occurs, since most chisels can be operated either by hand thrust, or be struck with a mallet.

In the next, and an important group, the chisel is controlled by the guidance of a stock of wood or metal, and becomes a plane. This is not a fanciful distinction, for ordinary chisels are so rigged up frequently in a temporary fashion, in a wooden block, for a special and temporary duty.

The fixing of a chisel in a plane stock gives rise to a large range of possibilities, as a study of the immense range of the plane group reveals. There are several scores of distinct types of planes, and made in different sizes. Most are used for producing plane surfaces, but large numbers have profiled forms, to reproduce the opposite sections, some sections being simple regular curves, others profiled, and moulded. Some have double irons, that is a break, or top iron in addition to the cutting iron. But from the point of view of angle, the principal thing to note is that the controlling face is no longer the face of the plane iron itself, but that of the stock in which it is rigidly embraced, and the iron does not lie flatwise on the work. Such being the case, we find great variations in the angles at which the irons are set in their stocks, the practical advantage of which is that the planes can be accommodated to the cutting of diverse materials, hard and soft, harsh, stringy and knotty, or mild and sweet. In most cases the bevel is set downwards, or next the face, bringing the sharpened facet nearly into line with the surface of the work being cut, giving an "angle of relief." In others the flat face is set downwards, and the iron is then fixed at a very low angle in the stock.

Following the chisel form into the working of metals—the softer kinds, as lead and copper, being excluded—there is no

example of a hand-operated chisel being used by simple thrust. Either the tools of this type are used percussively, as in the cold chisels, or if thrust, or drawn, it is done by the power of a machine. In each case the difference between metal, and timber and kindred soft materials is the reason for alterations in the cutting angles. These angles are much more obtuse for metal cutting, and they increase with the growing toughness and hardness of the metals, and depending also on whether a given material is being cut cold or hot. The percussive tools afford examples of this difference, the hot-sett of the smith and boiler-maker having keener angles than the cold-sett.

The principles underlying the angle of a cutting tool are these: The edge formed by the meeting of the upper and lower facets must be sufficiently keen—that is, must possess sufficient wedge formation—to penetrate and sever the material; it must also be strong enough to retain its keenness of edge with reasonable permanence, without the need of frequent regrinding. The friction between the work and the portion of the tool adjacent to the edge must be reduced as much as practicable, and so, too, must the friction between the severed chip and the face against which it comes in contact. The result is that tool formation is always a compromise, a balancing of conditions:—a keen cutting angle and reduction of friction being opposed to the strength and permanence of the cutting edge. Thus in Fig. 61, p. 58, which represents in profile a typical roughing tool suitable alike for turning and planing, shaping or slotting, it will be observed that the tool faces are all included a good way within 90°. If a tool filled up the angle of 90° it would not cut at all, but only scrape; nor would it have any clearance.

The proper starting point from which to determine the shape of a tool is the angle of clearance A, which varies in practice from 3° to 15° or even 20°. 5° should be sufficient in any tool, because that affords just enough clearance to prevent friction between the face of the tool and the surface of the work next it, and the less the amount given, the more permanent, of course, is the edge, because it is well supported by the mass of metal that backs it up. In some tool grinders 10° is a standard clearance angle, and it is probably a general average. One reason why very small clearance angles often exist is, that in hand-grinding, men will just touch the tool near the edges instead of grinding down the entire

face, and this tends to thicken the edge, just as a woodworker's chisel becomes thickened by sharpening a small facet, instead of rubbing across the whole bevel at which it leaves the grindstone. There is reason for this, but none for grinding a narrow facet only.

A great deal can be learned about these tool angles from the common chisel, and planes of the woodworker, operated in good and bad order, and on soft and hard wood, since they are cousins-german to the tools of the metal-turner. A much keener cutting angle on a chisel can be adopted than on the iron-turner's tool, simply because wood is softer than metal. The chisel has its angle of top rake, up which the shaving or chip curls (Fig. 10, p. 26). When the cutting angle of the chisel becomes thickened by repeated re-sharpenings, greatly increased force is required behind it to enable it to penetrate the wood. And a chisel ground and sharpened very keenly, cutting pine easily, will have its edge turned over against very hard wood, or its edge will sometimes even become notched and fractured, indicating the necessity for a slight increase in cutting angle. There is no front rake in the chisel; but, in fact, a workman usually tips the tool a very minute amount in taking a paring cut, and so intuitively gives a little front rake for easier working.

The angle B in Fig. 61, p. 58, which is that of top rake, governs both the incisive action of the tool, and the amount of freedom of movement of the severed chip, while the angle C—the tool angle—determines the strength of the tool and its permanence. The greater the slope of the top face the better for cutting fibrous metals, for reasons to be noted directly; but too much slope causes the tool to dig in, especially into crystalline metals and alloys. But the slope cannot be increased indefinitely, because the angle C would be reduced too much, with resulting weakening of the tool edge, which would be impaired rapidly. To realise these points it is only necessary to compare the razor, or newly-ground chisel for wood, with a tool angle of, say, about 15°, and a tool for cutting hard steel with an angle of, say, 80°. Average tool angles C, for average wrought iron, cast iron, and gun metal are 50°, 65°, 80°, or 90° respectively. The angles of top rake B, just now referred to, will range from 35° to 40° for wrought iron, 20° to 25° for cast, and 10° to zero for gun metal. But these can only be accepted as fair averages, though for convenience in shop systems, where grinding is done to gauge, it is

desirable and usual to settle certain angles and adhere to them. It is better on the whole as regards results, because it favours the use of tool grinders and gauges, and of some kinds of tool-holders.

The materials operated on by tools are hard, and soft, tough, and brittle, fibrous, and crystalline. Each occurs in extreme forms, and in a large range of intermediate grades. The variations in the character of these materials help largely to explain the action of the tools of different classes. Comparing at extremes, soft wood, or leather, and hard, or tough steel, or brittle cast iron, it would seem almost incredible that tools formed on identical principles should be capable of cutting these strongly contrasted substances.

The thickening of tool angles, therefore, cannot be considered alone, since it is related to the fibrous, crystalline, or other characteristics of the numerous and varied qualities of metals and alloys, and is controlled also by the angle of the cutting, and relief faces of the tool between which it is included.

A wide angle is a very different thing from bluntness of edge. An edge must be keen and sharp for severing metal, as for wood, but in order that the edge shall retain its keenness for a reasonable time, it must be backed up by sufficient metal; in other words, by a wide tool angle. This is the principle which underlies the formation of the various metal-cutting tools of the chisel type, as will be explained in their proper sections. Other requirements have to be fulfilled, of course, such as the power necessary to sever the metal, dependent largely on whether the material is removed in the form of shavings, or chips.

It is an axiom that if the severance of metal is to be effected with the minimum of power, then the more nearly the portion removed approximates in length to the surface from which it was taken, and the larger and longer the shaving, or the longer, and less broken up the chips are, the more nearly will this condition be fulfilled.

The distinction being shavings and chips is closely related not only to the nature of the material operated on, but also to the forms of the tools, and the various conditions under which they are used. To render this clearly understood by workers in wood, and in metal, the action of the plane iron can be compared with that of the tools of the iron-turner, and their cognate forms used on planer, or shaper.

Take two planes exactly alike with regard to the angles at which the irons are set in the stock, and sharpened exactly alike, the only difference being that one has a single iron—the cutting one; and that the other has two—the cutting iron, and the back, or top iron. The first will throw off rough shavings, and leave a roughly planed surface; the second will, if the top iron is set close down to the edge of the cutting iron, produce silky shavings, of an even thickness, and leave a smooth surface. And in proportion to the hardness, harshness, cross grain, knottiness of the timber operated on, will these differences be in stronger contrast. In fact, in the extreme conditions of hardness, &c., the use of a single iron is impossible, the case of certain iron-stock planes excepted.

The explanation of the difference is that the action of the top iron is coercive, that it bends the shaving over, and by causing it to turn, and curve, lessens the tendency of the cutting iron to tear or split the wood in wedgelike fashion. Putting it in another way, it resembles the difference between the combined wedging and splitting action of the axe, or adze, and the paring action of the chisel.

In the metal-turner's tools, we have the turning over of the shavings cut from those materials that are capable of bending, as the mild steels, wrought iron and copper, and in a lesser degree in the softer qualities of cast irons. It is in order to permit of this, that top rake is imparted to the roughing, and to many of the finishing tools. A larger angle of top rake would be given than is the practice, but for the fact that the tool would be weakened thereby. In theory the nearer the top face approaches the tangent to the work, the better for cutting. But as a wide angle—the tool angle—must be included between the top face and the front clearance angle, this limits the degree of slope which can be imparted to the top face.

The reason why greater slope is necessary for cutting fibrous metals like wrought iron, and the tougher steels, than for cast iron and brass, is that continuous shavings come off from the former, and chips, that break up instantly, from the latter. The shavings grind hard, and are curled against the top face of the tool, while the chips fall away directly. The more slope that can be given, therefore, to the tool face in the first instance, the better, while it is a matter of less importance in the latter. This accounts

for the common practice of turning brass with a scraping tool. The small chips fly off at once. But, all the same, it is better when roughing down brass to use a tool with some top rake. And, generally, the tougher the material, the greater in reason should be the slope of the top face of the tool, in order to permit the cuttings to roll off more easily.

This is the explanation of the yards of shavings that are readily cut off unbroken from these materials. If there were no top rake, shavings would not be produced, but broken chips. And when top rake is insufficient in amount, though the fibrous character of the material may ensure cohesion, sufficient to prevent the shavings from breaking into chips, yet they will be curled round into smaller, shorter, tighter spirals.

The test therefore of a true incisive tool having sufficient top rake is the production of large shavings of great length, and in the case of cast iron, where long shavings are impossible, the less of break there is in the chips, and the less sliding of the layers over one another, is the test of a proper amount of top rake. No shaving ever made in fibrous metals, measures, if straightened out, the full length of the surface from which it is severed, testifying to the fact that some crushing action always takes place.

In order to the better understanding of the angles of clearance, and top rake, we take a hand tool, which may be a graver, or a roughing, or finishing tool made of triangular, or square bar. Such a tool becomes either a cutting instrument, or a scrape according to the way in which it is presented to the work; the tool angle alone does not change. In Fig. 1 the tool is scraping, in Fig. 2 it is cutting. But while in Fig. 1 the angle of relief is so large that the tool edge will soon be lost, in Fig. 2 it is just right for almost any material.

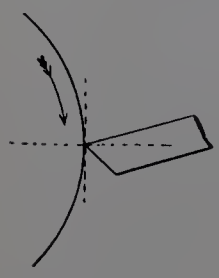


Fig. 1.

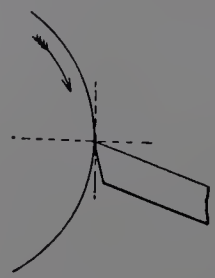


Fig. 2.

A safe way, therefore, to go to work is this. Settle a minimum angle of front clearance, which may be as low as 5° and need not exceed 10°. Then make the top angle, or top rake, as large as is found consistent with durability, and easy cutting of the shavings. In other words, give as much of incisive angle, and

chisel-like action, as the tool will endure, with permanence of shape. A mean can thus be struck, and embodied in tool-holders, and in settings for grinding in shop systems. All the experimenting and theory in the world will not get beyond these simple rules.

There is another aspect of this subject to which attention should be given. Returning to the plane iron, the rigidity produced by the screwing down of the top iron is as important a factor as its bending of the shaving. This belief is borne out by the fact that anything which diminishes chatter produces better shavings, and leaves better cut surfaces. An iron plane works better than a wooden one, because its mass absorbs chatter; many iron-stocked planes have single irons which could not work so sweetly in wooden stocks. Also the closer the top iron is brought down to the edge of the cutting iron, the less the chatter. Again, an iron that beds best on its stock, and that is secured best, works sweetest, *i.e.*, with less chatter. So that the function of the top iron is just as much that of preventing or lessening vibration, as that of bending the shaving.

In metal-turning tools also, we know that the more rigidly the tools are held, and the closer they are supported to the work, the less do they chatter, and the better is the cutting done. This is exemplified in many ways; in tools gripped in the slide rest, some with little overhang, and some with an excessive amount, in tools gripped in holders, in overhanging boring tools held in the rest, and in bars, and in boring heads. The better the support afforded, the less chatter, and the sweeter, and smoother, and heavier the cutting possible.

Tools of high quality have been used since the days of the Pyramid builders; and even long antecedent to that, the first flint chips were true cutting tools, the shapes of which embodied the same elementary principles of formation as the chisels and gouges used to-day. But during those thousands of intervening years no exact science of tools has been formulated, and so a great deal of what some would term empiricism still rules in the shops. There are no exact angles of cutting tools, and no exact formations of tool edges, of which one can say, confidently: "These are the best, and every departure therefrom is an error in practice." It would seem desirable in these days of formulæ to be able to put the problem of tool edges into a nutshell; but neither the writers on the subject, nor the practical men in the shops have yet accomplished

this. Either would have done it if the task had been easy; but the difficulties have been too great.

It is very easy to state the principles which underlie the formation of cutting tools—no one calls these in question. In the whole range, from the razor, with a cutting angle of, say, 15°, to those for cutting cast iron and steel with angles of, say, 60° or 80°, we find that two matters have to be balanced, one of which compromises the other—the maintenance of the maximum keenness of the cutting angle, with the maximum endurance or capacity of the tool to resist the loss of its edge. That remains the fundamental fact or principle—the basis which underlies the essential design of all cutting tools whatsoever. Going a step farther, it is also true that as a rule the softer the material operated on, the more acute can the angles of the facets of the tool be made; while, on the contrary, the harder the material the more obtuse must they be. But exactly what the angle should be to suit best any given material, apart from trial or previous experience, has not yet been made the subject of exact determination.

Quite as chaotic is the problem of what is termed the angle of presentation, and that of relief or clearance. We are prepared to find a considerable range possible to the latter, though there seems no good reason why it should ever exceed from 5° to 6°. But it very often does, and without any apparent detriment to the permanence of the tool edge. With regard to the angle of presentation, it seems as if some precise angle ought to be better than any others for a given class of material, both for effecting severance, and for clearing the stuff severed with the minimum of friction. Yet that has not been fixed, for those angles range within several degrees without appearing to be inconsistent with good practice.

The case stands something like this to-day. Men work in grooves. They find certain results follow from the use of certain tool angles, and then they lay down theories which harmonise with those results, and think that in so doing they have formulated rules of universal application. That is just where the error comes in; for the rule deduced, if universally applied, does not square with universal facts. For there are several conditions which exercise important influences on the operation of cutting tools, chief among which are differences in the physical characteristics of materials nominally the same, the effect of cutting speeds and

feeds, the support afforded to the tool, and, last, and equally important at least with the others, lubrication.

With regard to the first set of conditions, the denominations—cast iron, wrought iron, steel, and brass—tell but little of the physical characteristics of the materials which are classified by those names. Cast iron may have a toughness and hardness closely approximating to that of the quality of cast steel, or it may flake off in soft powdery chips. Obviously the tool best suited for dealing with one quality cannot be the best for the other. The same remark applies to forgings in different qualities of steel, and in a lesser degree to wrought iron. The gun-metals and brasses again range from tough, hard, and crystalline to soft qualities.

Taking next the question of speed, a high rate of cutting speed will rapidly grind away a thin keen tool-edge, and, therefore, rate, and depth of cut are both limited by the durability of the tool itself. But lubricate in quantity, and the edge endures even at a higher speed, and takes a deeper cut or coarser feed than without the lubricant. In extreme instances we find examples of rapid and efficient tooling done with cutting angles that appear incorrect in theory, results superior to those obtained with correctly formed tools and ordinary methods.

We find, therefore, that the subject of the angles of tools has in some degree been permitted to obscure other matters which are of equal importance. This does not imply that these angles should receive less attention, but that the other conditions should have more. Lubrication appears to be of equal value with angles, yet until recently it has not been studied and applied with one hundredth part of the interest and care that has been devoted to the former.

A secondary condition also which is studied to a greater extent now than formerly, is that of affording support to the work in opposition to the action of the tool. In older shop practice if this was ill supported, the feed of the tool was generally lessened, so reducing its efficiency. Now, one of the most striking differences between the design of the lathe tools of a few years since, and those of the most advanced practice of the present day, lies less in tool forms and angles than in the better support afforded, in conjunction with more complete lubrication. We have probably not learned much more about tool angles than Willis and Babbage

taught; but we are better acquainted with other conditions that also make for efficiency.

In the ordinary lathe there is but one way of opposing the action of the cutting-tool—that, namely, of a steady acting in the rear, or one encircling the work adjacent to the tool. Some few heavy lathes embody the duplex system, in which one tool is diametrically opposed to the other—an excellent device, but one which is obviously limited in its application. The balancing of cutting forces, or of rendering support to the work is now extensively carried out in the various box tools fitted to modern turret lathes, and in the hollow mills (Fig. 3) and kindred forms. The adoption of the same principle in screwing-dies renders their operation so much more rapid than that of cutting a thread in a lathe with a single pointed tool.

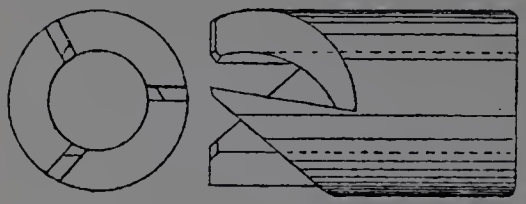


Fig. 3.

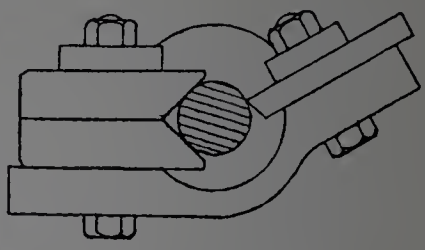


Fig. 4.

It is not necessary for high efficiency that forces should be balanced by the cutting tools themselves. If adequate resistance is offered to the action of a single tool, that is sufficient. To fit two or more tools for simultaneous action introduces complications which would for some work involve a too great expense. It is very often quite enough to use a single tool, and to support the work behind it with a vee'd guide (Fig. 4) following immediately after the cut,—our old friend the lathe-steady in a new and simpler guise. Supported thus, depths of cut of from $\frac{1}{2}$ in. to $\frac{3}{4}$ in. are constantly being taken with fine feeds.

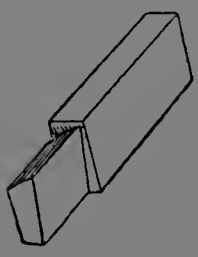


Fig. 5.

In the box the support is often more rigid than that of the lathe-steady, because both tool and guide are carried as closely together as possible in the very stiff box attached to the turret, and from which all possibility of spring is eliminated. The tools used for roughing are similar to those in the ordinary lathe work, or they resemble what are termed "knife tools" (Fig. 5),

and the box is their tool-holder. A small angle of clearance is given and an average cutting angle, and these tools are capable of removing broad shavings. In the most complete boxes, two, and sometimes three tools operate either simultaneously or successively on one piece, each tool having its own vee-support at the opposite side.

The slogging done with these tools could not be accomplished without the assistance of floods of lubricant. While writers on tools have long emphasised the evil of the rapid generation of heat, and pointed out the obvious advantages which would result from an ample supply of cooling fluid, the problem has been solved by the adoption of entirely new methods, familiar to many because they are now adopted in many of the more advanced English shops. They differ from the drip-can device in the immensely greater volume of lubricant, pumped in such quantity that it partially or wholly conceals the work being cut from observation. In the case of reamers or boring-tools it is pumped into the interior of the reamer, or into the recess being bored. Instead of soapy water being employed, lard-oil is frequently used, which, though costly, is yet economical, because employed over and over again.

The secret of heavy cutting must therefore be credited to lubrication and tool support equally with tool angles. Until within recent years machinists knew little of the possibilities that were hidden in these. Now they boldly attack large breadths of metal. Taken in conjunction with good average angles the tools feed with avidity, and that they are not being unduly stressed is apparent from the fact that they often retain their edges for several days, even though in constant use, without regrinding, showing in this respect also a far better record than common tools in lathe and planer operated under common conditions. This could not be the case but for the aids afforded by lubrication and support, however correctly the edges might be ground.

It is now well understood that lubrication can only reach its fullest efficiency when it is proportioned to the heaviness of the duty of the cutting tool. The harder a tool is worked, the more profuse must it be. The fluid used must also be supplied right at the edge of the tool, and be allowed to flow away at once, to be replaced continually by fresh, cool liquid. The broader the work, and the more rapid the feed, the more heavily are the cooling properties of the liquid taxed.

The advantages of lubrication are so great that in modern practice cast metals are sometimes so treated, brass quite commonly, and occasionally even cast iron, both of which are tooled dry in the ordinary practice of the lathe and machine shop.

In conclusion, the balancing of cutting forces, the giving ample support to work and to tools, and floods of liquid are the later features noticeable in the operation of cutting tools, and these to some extent diminish the importance which has been hitherto accorded to exact tool angles. The necessity of observing good average angles for given conditions of working is not neglected; but the point is that this is only one factor in the economies and efficiencies of cutting tools, and that others which are of equal value are those noted above.

A large number of tools that bear no external resemblance to the chisel, and the tools of this group used for cutting by lineal movements, possess the chisel action. But so many lie on the border line between cutting, scraping, abrasion, and shearing that we had better touch on these methods of operation at this stage.

When the working face, or the top face of a tool stands at an angle of 90° or more with the face on which it is operating, or with the tangent to that face in circular work, it is not a cutting tool, but a scrape. Such tools are frequently used for turning brass, and for finishing smoothly the surfaces of iron and steel, which have been previously roughed out with cutting tools. The cabinetmaker's toothing plane is an example of a scrape for wood. Final correction, and finish-frosting is put on metal work by scrapers, which remove extremely minute quantities of metal. But the chief interest centres round the action of the scrape in a larger variety of tools, represented by taps, dies, some saws, and files. Abrasion, so called, by the gritty points of grindstones and emery wheels, may seem a small matter, yet it looms large in present practice, and in fact we must consider it as a true cutting action. Shearing is an operation which takes place when a shaving or a sheet of metal is severed in detail, or diagonally, instead of by a straightforward, or sudden cut. The detrusive action of a punch may, or may not partake of a shearing character. In each case a tool angle may be present, or not.

We begin to see how complicated the queston of tool angles may become. There are several tools to which it is difficult to assign an exact place, tools which are not true cutting instruments,

if measured by angle, but which nevertheless do operate in effect as such. In the attempt also to impart cutting angles to some, other evils are magnified. Shearing and cutting are sometimes combined, one to counteract the other, or both to operate in unison, and help each other. In saws we have examples of cutting, and of scraping teeth, the first for ripping soft woods, the second for ripping hard woods, and cross-cutting both kinds. The teeth of files are scrapes. The teeth of taps, and dies, and of milling cutters are generally scrapes, but some have a slight rake which brings them under the head of cutting tools. Some drills are scrapes, others are true cutting tools, with shearing action in combination. Most tools for wood-boring cut, but not all, and of those which cut, many suffer by reason of the cutting forces being unbalanced. These and cognate problems will receive illustration in the various sections of this work devoted to particular groups of tools.

SECTION I.

THE CHISEL GROUP.

CHAPTER II.

Chisels and Allied Forms for Woodworkers.

tiquity of Chisels—Primitive Forms of Stone, Bronze, and Iron—Single and Double-bevelled Chisels—Cutting Action — Angle and Edge — The Wedge Principle — Splitting Action—Operation by Thrust or Pressure—and Percussion—Importance of Rigidity—Angles of Grinding and Sharpening—Skill required for Operation—Methods of Holding—and of Thrusting—Grain—Plane Surfaces—Paring and other Chisels compared—The Axes and Adzes—Control of—Draw-knife—Carvers' Chisels—Lock Chisels—Turning Chisels—Sharpening Chisels—Permanence of Edges. The Gouges—Antiquity of—Outside and Inside Types—Firmer and Paring—Millwrights' and Coachmakers'—Curves of Gouges—Value of Paring Gouge—Carvers' Gouges — Their Varieties — Method of Operation — Turning Gouges—How to Use.

THE chisels are the oldest tools, for Paleolithic men used them in the form of axes, roughly chipped from flint, while the severed flakes served as tips for javelins, and lances, and for the first rude drills used by man. The Neolithic men improved on these primitive tools by the practice of grinding and polishing their celts (Latin, *celtis*, a chisel), and in a crude fashion they seem to have differentiated true chisels and gouges from the axe-like celts, besides which many examples of hafting occur. But they at first hafted with a hole in the handle, into which the celt or other implement was secured, being easier than drilling a hole in the stone. To lessen risk of the handle splitting, the hole was made a considerable distance from the end (Fig. 6). The two were often secured with vegetable fibre.

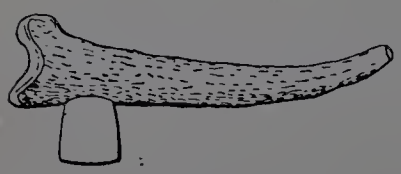


Fig. 6.

The older axes were of stone, and driven into their handles. The modern one is of steel, and the handle is driven into its eye—a most important difference. Apparently thousands of years passed before the present method of handling occurred to the minds of tool-users.

The true chisel, handled for direct thrusting by the hand, is late in point of time. Apparently such tools were unknown until long after men cast tools in bronze. Then we find the true chisel, and the gouge.

The axe, therefore, is the oldest of all tools—older than the adze, or the chisel, or the drill—and, except in the material, and the manner of handling, it resembles the modern one.

While flint was chiefly used in the Paleolithic times, the Neolithic men also employed beside flint, basalt, greenstone, serpentine, porphyry, micaceous grit, for their celts.

Not until men had acquired the art of casting in metals was any further advance possible. But the Bronze Period of human culture is exceedingly rich in chisels, axes, and allied forms, which bear unmistakable resemblances to those of the present time. Palstaves, tanged, and socketed chisels, and gouges are abundant, and many of the moulds in which they were cast have also survived. A few similar forms in iron of a later date have escaped the ravages of rust. In the ancient Swiss lake dwellings iron axes, with holes for the wooden hafts, have been found.

The bench chisel—type of others—differs from the chisel used for turning, or the axe, in the fact that the wedge formation given to it is imparted by bevelling one face only. In this respect it resembles the adze. This distinguishes it from those tools in method of operation, inasmuch as the chisel will pare a fairly true surface by the control of the hand in conjunction with the flat face of the tool. But this also involves the necessity of keeping the cutting face perfectly level.

The chisel having a single bevel only is late in point of time. It marked a great advance, because the unbevelled face became a guide to accurate work, differing from a doubly bevelled tool, such as a celt, or a cold-chisel type, of which numerous examples in bronze remain. A good deal of correction in the way of removing fine chips and scraping must have been necessary with such tools.

The difficulty of cutting effectively with the ancient chisel of

stone, and even of bronze, seems to indicate that these tools were seldom if ever used otherwise than percussively, of which the axe and the hatchet are the modern representatives. In the case of the smaller chisels there is evidence of the use of the mallet in the burred-over heads. So that really three of the most important tools of the chisel type are operated by our carpenters to-day much as they were actuated many thousands of years ago.

Chisels are used in all the woodworking, and in many other trades besides, yet each trade has some forms peculiarly its own. Among these are included carpenters, joiners, pattern-makers, millwrights, coach and waggon builders, turners, coopers, masons, slaters, bricklayers, sculptors, engravers, butchers, and so on. Most of these chisels are furnished with handles, and the handles differ also from one another in several respects, depending on the method of use of the tools. (See Chap. XVI.) The proportions of blades in respect of width, and length, and cross sections also vary widely.

The action of this great family of chisel tools is that of cutting, the condition of which is that one face lies parallel or nearly so with the face being cut, and the bevel makes an angle therewith, which may range from 10 to 30 degrees. The razor, the shoemaker's knife, and the table knives are chisel-like tools with the smallest angle, while axes have the largest angle among the true chisels.

It is necessary to distinguish between angle, and edge. A keen angled tool will not cut shavings if the edge is dulled. Sharpen the edge on the hone, without altering the angle, and the tool cuts shavings sweetly. If the tool were acting as a wedge only, splitting by percussive blows, the state of the edge would have no influence, but the angle of the wedge only.

But the degree of keenness of edge is related to angle, when materials of different kinds are being cut. A keen edge is equally desirable for cutting soft pine, hard oak, harder lignum vitæ, or hardest iron and steel, but the tool angles have to be different in each, to back up the edge properly; and by supporting it to its work, they prevent it from being crumbled or broken away. A chisel angle suitable for cutting wood, will cut lead, and copper easily, and tin with some difficulty. Very minute cuttings can even be taken off well-annealed malleable cast iron. But ordinary irons and steels cannot be touched except by adopting larger

angles, and using percussion, as in the cold chisel, or by making the rotation of work effect much of the necessary pressure, as in hand turning, or by adopting the mechanical help of the slide rest to keep the tool up to its task. The mere thrust of a tool, sufficient in wood cutting, is impotent to sever hard metals, however keen the edge may be, and however wide the tool angle.

The wedgelike action of a chisel is comparable with that of an inclined plane, in which the labour of drawing a weight up the slant face is less than that of lifting it perpendicularly; in the proportion which the length of the inclined plane bears to the perpendicular height. A wedge may be regarded as two inclined planes placed back to back.

Tools of the chisel type embrace a very great number of forms, diverse in appearance, and in mode of application, yet having a common affinity to the wedge. A wedge may possess the splitting property merely, or it may divide by cutting, the difference depending partly upon its degree of obtuseness, partly upon the manner in which it is presented to the material, partly also upon the nature of the material operated on. Thus, an axe if driven into the end of a piece of wood, in the direction of the grain fibres, will not actually cut, but will divide the wood by splitting alone. But if it be employed at the face of the wood, where the layer of fibres is so thin as to yield readily, the purely cutting action will predominate. The same remarks will hold good of a chisel used in the same way. But if the wood is to be divided in a direction transversely to the fibres, neither axe nor chisel will operate by splitting, but the cutting action must of necessity be continuous throughout, and then the saw is used.

The chisel, therefore, used as a splitting tool is the oldest type, its most familiar representative being the axe, which is a wedge pure and simple, no cutting action occurring after the first entrance of the edge. The line of cleavage then lies in advance of the edge, the fibres being forced asunder, and the edge does not cut at all. Such action is widely different from that of paring. It is only of value in splitting up fairly straight-grained stuff, its most familiar example being chopping wood, and rending builders' laths. In crooked grain and across the grain it is of no value, nor for any substance but wood. Such action has little in common with the bench chisel, the edge of which is instrumental in removing a shaving, thick, or thin, away from the cut surface. The chisels

actuated by a direct thrust, and those in which the force expended takes place at right angles with the axis of the chisel, correspond with another classification. All the early chisels belonged to the latter, being furnished with handles or hafts, as our axes and adzes are to-day.

As all the chisels are used in one of two ways, being either thrust to their work by simple pressure, or driven by percussive action, this distinction is embodied in the proportions of these tools, and to a slight degree in their cutting angles. Percussively acting chisels, which have to stand the mallet, like mortise chisels, or have to be driven by the swing of a lever, like the axe and adze, must be made stouter than the paring tools which are simply thrust, or they would become fractured by the severe concussions to which they are subject. Their cutting angle must also be slightly more obtuse, or the edge would be lost, either by simple dulness, or by the breaking out of fragments of metal, especially in tools that have been tempered rather highly. This difference is not so apparent in the simple action of paring, as it is when the tools are used more in the character of wedges, deeply buried in the wood, and acting partly by cutting, but often more largely by cleavage.

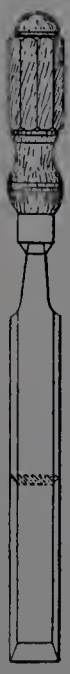


Fig. 7.

The exact degree of cutting angle of chisels is generally disguised by the fact that the sharpened angle is greater than the ground one. But a wider angle is usually adopted for percussive work than for simple pressure, and for operating on hard, tough, stringy woods than on soft, open grained ones. It is always much less than the angle for metal-cutting chisels, *e.g.*, the cold chisel, the turner's and planer's roughing tools, knife tools, and others that remove shavings from metal.

Many tools of the chisel family are operated indifferently by pushing, or by percussion; as for example the firmer chisels, and those for millwrights, coachmakers, and others. But in the extreme types there is but one method of use adopted. Long, thin, paring chisels (Fig. 7) are seldom struck by a mallet. They are liable to fracture, and even if they do not break, they spring. Neither are draw-knives, or turning chisels ever struck. But the axe, and the adze group are always used percussively, and so are many others.

The efficiency of any chisel depends to a considerable extent on its rigidity. This is apparent when attempting to cut thick chips with a slender paring chisel. It springs, and would chatter, and jump away from its work if forced hard. In an extreme case, try to slog out a mortise with a paring chisel. To cut mortises properly, an extra stout chisel is made for the purpose (Fig. 8), which will neither spring, nor snap under the heaviest work. It is very thick—nearly square in cross section—while the paring tool is very thin, and often also has its top edges bevelled, as in Fig. 7. Then the handle in the latter is comparatively slender, while that of the former is massive. That of the paring tool is bellied, to be grasped easily in the hand; that of the mortise is of no particular shape, since it is simply steadied and controlled by one hand, while the blows of the mallet are delivered by the other. If paring chisels are struck by the mallet, as they are sometimes, the blows must not be severe, or the jar is liable to snap them. To pare with a mortise chisel, on the other hand, is almost impossible. Midway between the extreme types are the firmer or short chisels, and the coachmakers' chisels (Fig. 9), which have to stand some hard duty imposed by the concussion of the mallet; and the turning tools, which are fitted to withstand occasional concussion, besides the steady strain of deep cutting.

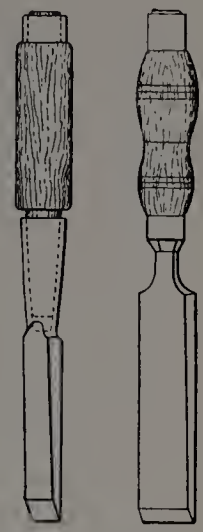


Fig. 8. Fig. 9.

The bevelled face includes the ground bevel, and the sharpening bevel, the first of which remains constant, the second always tends to increase the cutting angle, due to re-sharpening. On first sharpening a newly ground chisel, there will be little difference in the angle of the grinding and sharpening, and at that period the tool cuts most sweetly. When by re-sharpening the angle becomes thickened to such an extent that cutting is not sufficiently free, or re-sharpening takes a long time; then it is more economical to re-grind.

The angles at which chisels and gauges are sharpened should vary a little with the work on which they are used, and also slightly with the known temper of the tools. Tools are sometimes so hard and brittle that it is impossible to grind them thin; for contact

with a knot, or a slight amount of malleting suffices to break pieces out of the keen cutting edges. But if ground more obtusely they form splendid tools, cutting sweetly, and keeping their edges good. Other conditions being equal, tools used on soft wood will bear more acute grinding than for hard woods. This is no more than we should expect; but the error consists in supposing that a tool *sharpened* "thick" must needs cut well on hard wood. It will not, since the edge has little penetrative power. We must not ignore the wedgelike action of the tool. A chisel will also cut more sweetly, if instead of being forced directly downwards, or across, the wood as the case may be, it is moved in a slightly oblique direction. This combines the wedgelike, with the shearing action, and produces a clean cut face, even though the edge happens to be a little dulled. It will be found also that less muscular effort is required.

The chisel in all its forms requires more skill in its manipulation than some other tools, such as the plane, or spoke-shave, because the degree of accuracy of its operation depends on the control afforded by the workman's hands; it is also less easy to control the percussive chisels, as the axe and the adze, than the paring tools. In paring, the tool is set or placed against the face, or the line to be cut by, as in Fig. 10. In the axe and adze the eye determines the location of the blow delivered by the hand—a task requiring skill born of practice. A man unaccustomed to the adze can do nothing accurate with it; one skilled in its use will control its action within a sixteenth of an inch. The training of the hand and eye is a mutual one. The direction and extent of a percussive cut cannot be altered after it is once started; that of a paring tool can. Thus the latter is capable of producing the more accurate results. In order to produce the best work with the axe, using it as a trimming tool, rather than as one for splitting, the single-grinding bevel should not be departed from in sharpening. If the bevel for sharpening is different from that of grinding, the power of control is lessened. The advantage which the adze possesses over the axe for correct work is due to the fact that all the bevel is on one face; the face in contact with the work being cut is not ground at all. It would be flat, but for the necessity of imparting a convexity to that face (Fig. 15, p. 30),

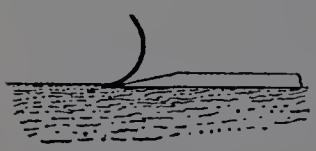


Fig. 10.

about equal to the radius through which the adze is swung. The difference between these tools and the chisel having one face quite flat is apparent, and the nearer they resemble the chisel the more accurate will the results be which they produce.

The way in which a chisel should be held when in use depends on the position of the work. Most cutting is done with the tool held perpendicularly, the work lying on the bench. When paring vertically, the wrong way to hold the chisel is to elevate the elbow, and grip the handle at the end and press downwards with the palm of the hand. That is the method of the beginner. The right way is to clasp the body of the handle in the closed hand, with the elbow slightly depressed, and to exercise pressure downwards in the direction of the axis (Fig. 11).

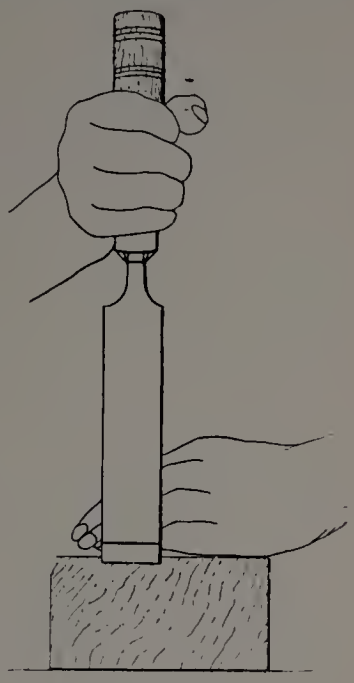


Fig. 11.

The chisel edge generally has to be set into lines scribed, or otherwise marked on the surface of the work. So that while the right hand is thrusting the chisel, the left is controlling its cutting edge by resting partly on the work and partly against the chisel. Of course, after the lines have been set in, the cut surfaces afford sufficient controlling influence. A fair amount of work is also held in the vice, and the chisel held horizontally. To cut thus, the wrong way is to grasp the body of the handle; the right is to grip

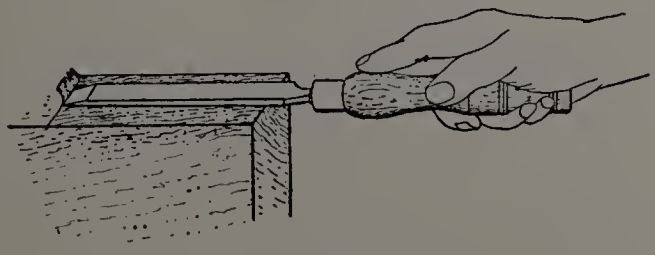


Fig. 12.

it at the end, and to thrust it forward with the palm of the right hand, steadying it, if need be, with the left (Fig. 12). To pare

small work held in the left hand, the chisel is grasped by the body of the handle (Fig. 13).

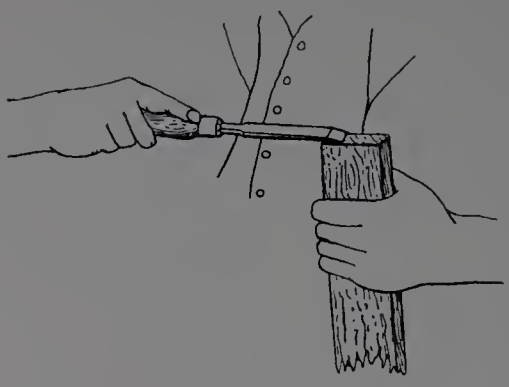


Fig. 13.

The direction of thrusting a chisel has much influence on the results. When cutting vertically above the bench as in Fig. 11, the effort is little more than that of the muscles of the arm. But when cutting horizontally by thrusting (Fig. 12), much of the weight of the body can be thrown into the work. One hand only can be conveniently used in a vertical cut, but two may be frequently employed when shaving horizontally.

The chisel is ill adapted for cutting along the grain with any great precision, though suitable for roughing-down in that direction. If the grain is not very straight, the tool will follow it, and tear up the surface in those places where the fibre runs downwards or away from the cutting edge. Then the work must be reversed, and when that is not practicable, very thin and light cuttings only must be removed. A chisel working across the grain avoids these evils, but the surface left is not smooth—a shearing cut being required. The cutting of end grain is most satisfactory, since that can be left very clean and smooth and true, provided the chisel is quite sharp.

The force required to operate a chisel varies with its width, and with the thickness of the chip, and therefore there comes a limit to its effective operation by hand. A width of $1\frac{1}{2}$ in. is about as much as one can use in cutting chips of moderate thickness, combined with the production of a reasonably true face. To sever thick chips of such a width is hard work. To remove those of, say, $\frac{1}{4}$ in. thick, even with a narrow mortise chisel, is beyond the power of the hand alone, and so here the mallet is brought in.

No chisel possesses such perfect guidance as the planes do, and yet by practice, surfaces of three or four inches in width are constantly being finished by the chisel alone. Here the value of the paring tools over the firmers is apparent. A firmer chisel is a stumpy article to use for broad cuts. One has to work in a more

cramped posture with it than with a paring chisel. The latter, moreover, can be kept flat on the surface being cut for a length of several inches, provided the chisel has a nice straight face. It should never be tipped up on that face when sharpening. Frequently an end can be finished more neatly by holding the work in one hand, and taking very light cuts, as in Fig. 13, turning the wood about, and cutting first in one direction, and then in the other.

Since a paring chisel is so slender that it springs in the longitudinal direction when the attempt is made to cut deeply with it, especially on end grain, here therefore the millwright's or

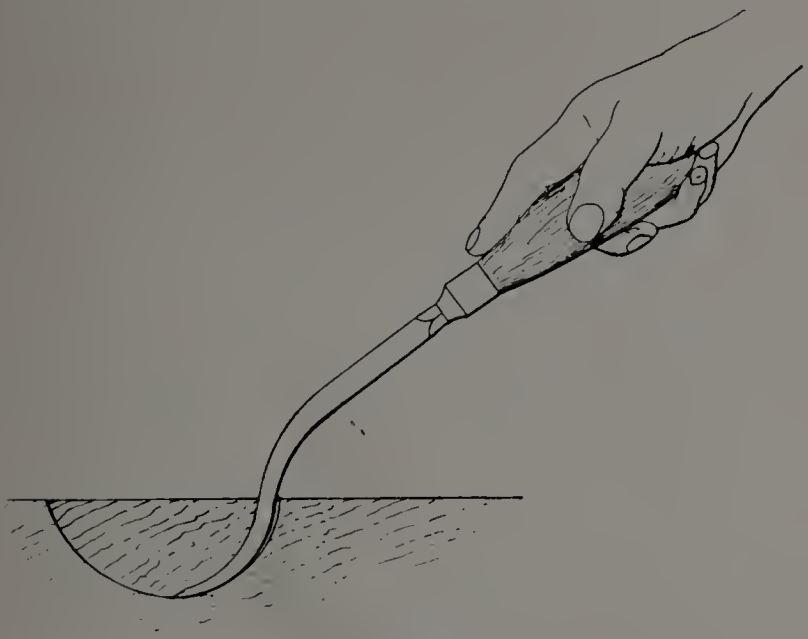


Fig. 14.

coachmaker's chisel (Fig. 9) fills a valuable place. This is used both as a paring chisel in heavy cutting on hard woods, or for medium heavy malleting. In this respect it occupies a place between the firmers, the mortise chisels, and the paring tools.

The chisels which are regularly driven by the mallet are much stiffer than the millwright's and coachmaker's. They include principally the tanged mortise, and the socket mortise chisels (Fig. 8), made in their several varieties to suit different trades. Though differing in length, all alike are characterised by a thickness approximately twice or three times as great as that of the firmer, and paring tools. They have a very marked amount of

taper, so that they can be malleted, and also used as levers to push the chips back from the cut face, and to dig them out of their holes. Proportions vary, thus :—

Fig. 15.

A cabinetmaker's chisel is rather lighter than the carpenter's. A sash chisel is made more slender than the carpenter's. The chairmaker's tool is shorter, and more stumpy than either. A mortise chisel used for locks is bent similarly to the carver's in order to permit of scooping out the chips (Fig. 14). In the socket types, variations occur in length, and in substance. These will stand more punishment than the tanged chisels, the sockets lessening risk of splitting the handles by hard malleting, and in that their chief value lies. Except for cutting, and clearing away at the finish, these tools are invariably driven with the mallet.

Fig. 16.

Fig. 17.

Many chisels have their back or upper edges bevelled (Fig. 7), to permit of cutting along within the edges of acute angles, as those of dovetails. An alternative to this form is a convex back, less used however than the bevelled.

Fig. 18.

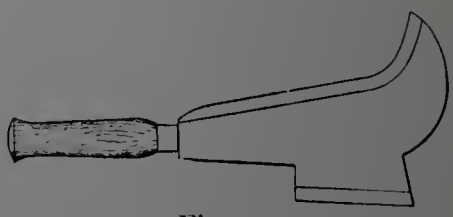


Fig. 19.

That large group of the chisel family which, though percussive, is not actuated by a mallet, but by the swing of a lever, includes the adze (Fig. 15) and the axe (Figs. 16 and 17), the various choppers (Fig. 18), and cleavers, the bill hook (Fig. 19), the

chisel-pane hammers (Fig. 20), boiler scaling hammers, and allied forms. The width of blade in most of these considerably exceeds that of the chisels. There is no guidance at all for starting an operation, but cutting to a line is a work of skill on the part of the craftsman. And yet in the case of the axe and adze, very close results can be obtained. Cleavers, choppers, bill hooks, and the lath-hammer, or lath-render (Fig. 21), are employed as instruments for severance only, or chiefly, but the adze and axe are in a sense finishing as well as roughing tools. Within their sphere they are unapproachable by any tool whatever, that sphere being the shaping of rough balks and branches of timber into straight and curved outlines for various purposes.

Fig. 20.

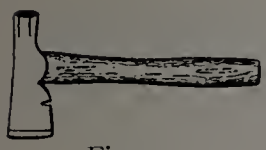


Fig. 21.

Adzes are used by shipwrights, carpenters, coopers, wheelers, platelayers. They differ in length of blade, in curvature, and in the formation of the head, which is generally finished to serve as a hammer.

Axes or hatchets are made in many forms, each with its distinguishing name in the trade. The most marked difference occurs perhaps in the English, and Yankee pattern (Figs. 16 and 17 respectively).

The efficiency of adze and axe depend to a large extent on the long swing of the handles, by which they are distinguished from most of the other chisel-like tools. In those which resemble them most nearly, the butcher's cleavers, meat choppers, and bill hooks, the handles are much shorter; but the latter score in greater length and weight of blade.

The utilities of the chisel family are not confined to the obvious one of removing shavings or splitting. A bricklayer's axe for example is a broad knife by means of which a nick is produced around the brick, after which a blow of the hammer severs it. The slater's saxe (Fig. 22) acts in a similar fashion by nicking, and other examples occur to the mind.

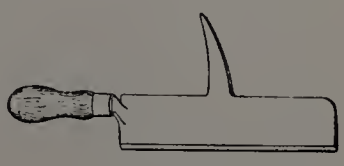


Fig. 22.

The pick in its various forms is a chisel in which the point takes the place of an edge. It does not sever, but splits. It is a cleaving, not a shaving tool. The coal pick, and the navvy's pick

are tools in common. Somewhat similar is the marline spike used for forcing the strands of rope apart when splicing.

A miner's, or rock drill (Fig. 23), is a percussive tool;—in effect two chisel points at right angles, which is turned upon its

Fig. 23.

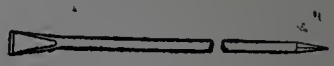


Fig. 24.

axis, and thrust to the rock which it breaks up. A quarry jumper is a single chisel edge (Fig. 24), operated similarly.

Only in a slight degree do any of these tools possess guidance in themselves, even after a cut or a split is started, for they have no flat faces like the firmer, and paring chisels possess, but are either doubly bevelled as in the axes, or the cutting face has considerable curvature as in the adzes (Fig. 15). After the cutting of a face has commenced, the portions first cut help to control the movements of these tools, which are arrested by the cut faces. The surfaces left are short facets, each one formed independently of the others, differing in this aspect from the face left by a chisel, which lies flat upon its work. The degree of control exercised upon the axe and adze makes all the difference between good and poor results, and this has to be acquired; the tool formation rendering no aid as it does in the chisel, or in a more complete manner in the planes. Both axe and adze tend either to "strike off" from the work, or to stick fast in it. The first happens when fine cutting is attempted, the second when slogging is being done. Cutting of the latter class partakes more of the wedge, and less of the chisel action, of splitting more than of shaving. In using a hatchet, a little support can be

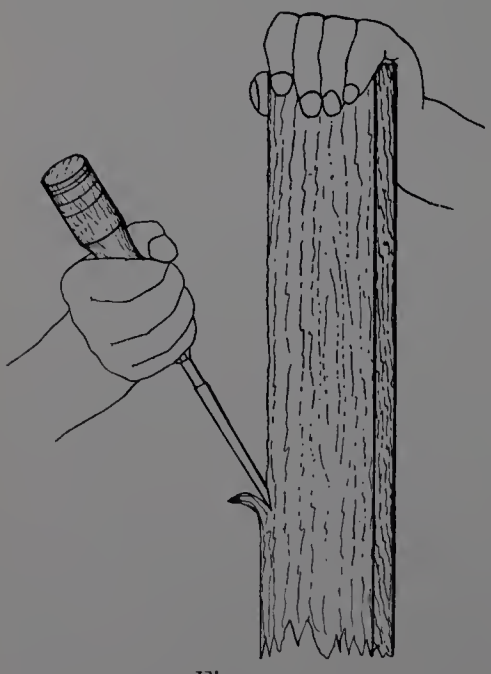


Fig. 25.

derived by keeping the right arm close to the body, but in using an adze, support is obtained by resting the elbows and arms close against the ribs. After considerable practice a man may become more expert with the adze, than with the axe.

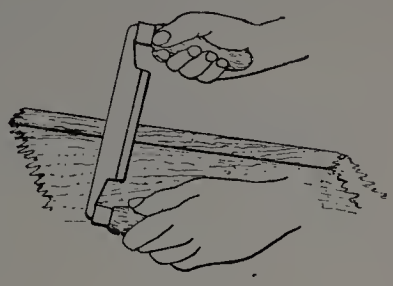


Fig. 26.

A chisel is often used as a roughing tool on the bench in place of the axe. Pieces of wood that have to be turned down between centres have their keen angles cut off with a chisel, as being more rapid in action than the plane, with the stuff laid in an angle board. Chips are cut off with the chisel face next the piece, the work being pressed against the bench stop. Or often the back of the chisel is employed to rough down an edge preparatory to planing, the stuff being held vertically (Fig. 25), the mode of cutting then resembling that of the axe.

The draw-knife (Fig. 26) owes much of its value to its two handles, which enable both hands to be utilised, so that very thick chips can be cut off the edges of boards held in the vice, being almost as stout as those which an axe would cut. And the draw-knife is simply a very broad chisel fitted with two handles, by which the tool is pulled or drawn towards the workman.

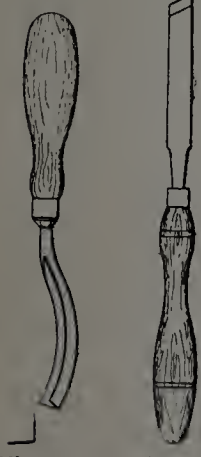


Fig. 27. Fig. 28.

Draw-knives occur in several patterns, and sizes, straight and curved in the blade, and with handles parallel, or divergent. Carpenters, joiners, mastmakers, wheelers, and coopers use them.

The intricacies of wood carvers' work are reflected in a number of tools, all of small size, but greatly varied in outline. There are straight chisels, square across the cutting edge, and skew, or on a bevel. There are also spade chisels, both square, and skew. The vee tools, or parting tools (Fig. 27), are in effect two chisels set at various angles, acute, and obtuse, for cutting angular grooves of corresponding shapes, and these are both straight and curved longitudinally. The dog-leg chisel comprises a narrow chisel formed at the end of a long cranked shank.

The turning chisel (Fig. 28) is an example of a mixed character.

Its guidance does not depend on the sharpened faces, since it has a double bevel in the style of the axe. Yet it is not a percussive tool, and it is not thrust with much force to its work. It is held, controlled, and guided by the hands, in combination with the support afforded by the rest (Fig. 29). It does not cut over its entire width, but only over one-third or one-fourth of the same. Its action is so keen that it will cut with or across the grain, or on end grain with almost equal facility.

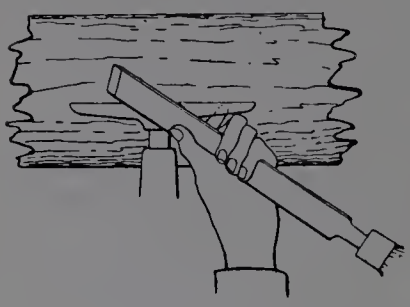


Fig. 29.

Fig. 30.

The gouges are true chisels, curved in cross section. The remarks that have been made about the difference between firmer and paring tools, of chisels operated by thrust and by percussion, apply to gouges. The latter, however, do not occur in so large a range of sub-types, neither are the adze and axe-like tools represented among the gouges.

Gouges of bronze occurred in great numbers in the Neolithic Age, some being of the tanged, others of socketed types (Fig. 30). The idea of curving the chisel to enable it to form concave profiles is therefore some two or three thousand years old.

There are two great groups of gouges, the outside and the inside, the terms denoting the method of grinding; the outside gouge having its bevel for grinding and sharpening on the convex or outer face, the inside gouge being ground on the inner or concave face. The former group are also firmer or short gouges, the latter are paring or long gouges, the relative lengths of which have their analogies in the firmer and paring chisels. The paring gouges were developed by the necessities of the millwrights and patternmakers, and they are, like the chisels, made stout and heavy, and thin and light.

The firmer and paring gouges are used like the chisels of the same name, the firmer chiefly with the mallet, and the latter by hand thrust or pressure almost wholly. Exceptions occur in the millwright's or coachmaker's paring gouges, which are made stiff enough to endure malleting, and in a small group of firmer gouges, which is ground inside instead of, as usual, on the outside.

The curves of the paring and firmer gouges are divided between groups, so that a gouge of any one width can be obtained in either one of six different curvatures. Formerly there were three available, quick, flat, and middle flat, but now a range of six is obtainable, designated as A, B, C, D, E, F groups. Two of these, the extremes, are shown in Figs. 31 and 32 for gouges up to 1 inch in width. Gouges are made from $\frac{1}{8}$ to 2 inches wide, but the generally useful sizes are included between $\frac{1}{4}$ and $1\frac{1}{2}$ inch.

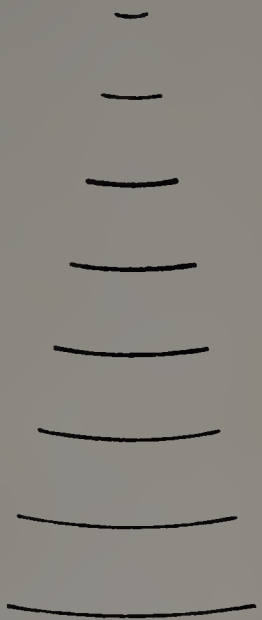


Fig. 31.

The paring gouge is very valuable not only as a finishing tool but as a roughing-out tool. There is a great deal of work which cannot be put under the band saw, and for this a broad quick gouge is the best possible slogger. What are termed the "trowel shank" or "spoon gouges" are excellent forms for this, because the knuckles do not come in contact with the work. As in chisels, the working face of a paring gouge must be true, if true cutting is to be done.

A great group of gouges is that used by carvers. They include straight gouges in numerous sweeps, and gouges curved in the longitudinal direction, capable therefore of cutting concave shapes in two directions;—that corresponding with the curve of gouge section, and the other variable, but to some extent controlled by the longitudinal curve of the gouge.

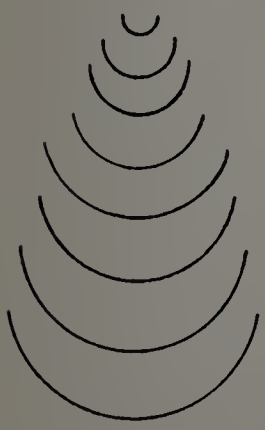


Fig. 32.

Fig. 33.

The carver's gouges may be ranked as firmer gouges, being all short, but they form a class alone, since, though some are straight lengthwise, the great majority of them are curved or "bent" in that direction, the object of which is to permit of their cutting into curves of very small radius, in the longitudinal direction of movement of the gouge. They are "front bent," and they are "bent back"; made also with long curves, and with short quick ones, or "spoon bit" (Fig. 33) and "spade" type, and each in a

wide range of sizes, from extremely flat forms to "quick," up to half circles. The widest of these tools do not exceed about $\frac{3}{4}$ in. in breadth. Extreme sectional curves are shown in Fig. 34.

Fig. 34.

Patternmakers use some of the carver's tools, chiefly the curved, and front bent gouges, for cutting the interiors of core boxes, especially for the "hollow" portions, or radii of recessed, or chambered, or shouldered parts of boxes.

The carver's tools are driven by the mallet in roughing out, but in finer cutting they are more often thrust by the ball of the right hand, concussively, and in finishing cuts they are simply held in, and thrust by the hand.

The turning gouge is shown in Fig. 35. In the hands of a professional wood-turner a simple gouge is a marvellous tool, producing hollows, ogees, and mouldings of various shapes with swift dexterity, aided only by the chisel where sharp corners are concerned. Those who handle the gouge with confidence and skill can turn out their work quicker, cleaner, and better than those, who, dreading a disastrous "kick," or "catch," scrape away cautiously with the round nose, and chisel, and diamond point. An inch gouge, that is 1 in. wide, is the largest that can be well used with a light treadle lathe, and to use that effectively means hard leg work. A $\frac{1}{2}$ in., $\frac{3}{8}$ in., or $\frac{1}{4}$ in. will be more generally useful by far. The gouges should be well rounded in grinding (Fig. 36), so that the point, and not the corners shall be used for cutting, and they, in common with most of the other tools, should be furnished with long handles, to afford adequate leverage and control.

Fig. 35.

Fig. 36.

In turning straight along, either between centres, or on the face plate, the gouge may be held flat on its back without any danger of its catching in the wood; but, in turning mouldings, and in boring holes with the cup chuck, the tool must be held sideways, and the corner of the gouge which is lowest, or rather some portion of that half the gouge which is lowest, is the one which will be used for cutting, the higher corner being kept carefully away from the revolving

wood to prevent a catch. Even, however, in rapidly roughing down plain straight surfaces, it is advantageous to handle the gouge in this fashion, using both sides alternately, since it cuts the wood cleaner, quicker, and with less friction than when used on the flat. This is a lesson only to be learned by practice. The great thing is to *feel* the work. Thus, if turning down a moulding, or a ball at the end of a curtain pole, from circumference towards the centre, there is the centrifugal force very sensibly tending to thrust the gouge outwards, and this, of course, is the force which must be resisted. The point of the gouge, or a portion just below the point, will be used, as offering least friction, and the tool must be grasped *very firmly*. In turning a flat surface, no such force exists, and the gouge may be held indifferently in any position, and comparatively slack. Always the end of the gouge handle is held in the right hand, while the three last fingers of the left grasp the lower portion of the gouge itself. The requisite guidance is imparted to the tool by the thumb of the left hand, while the opposite forefinger passes underneath the rest, in opposition to the thumb, thus gripping the tool as in a vice. Lastly the rest must be kept close up to the work.

CHAPTER III.

PLANES.

Great Variety in—Setting of Chisel or Iron in its Stock—Fastening of the Iron—Convexity of Same—Choking—Utility of Top Iron—The Question of Angles, as affected by Re-sharpening—Linear Guidance—Related to Length of Stock—Preservation of Truth of Face—Planes for Concave Sweeps—The Profiles of Planes—Drawbacks to the Moulding Planes—Iron Planes—Gripping of Planes—Pressure on—Guidance of—Aids derived from Shooting, and Angle Boards—The Aid of Strips—Checking the Truth of Planed Surfaces—Details of Planing—Faces—Ends—Setting Irons in Stocks—Removal of Irons—Good and Bad Timber—Sharpening Moulding Planes—Wear and Tear of Planes—Shooting—Mouthpieces—Selection—and Preservation of Planes—Toothing Planes.

A CHISEL, to possess linear guidance, must have its flat face coincident with the surface being cut. Thus, it would be impossible to cut the surface A, Fig. 37, truly with the chisel held at an angle, as there shown. But if it is inserted at an angle in a stock, it becomes a plane, which produces true surfaces beyond the capacity of a mere chisel to operate upon.

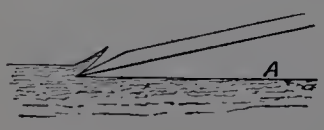


Fig. 37.

The mechanic who first put a chisel in a wooden stock to supplement the uncertain control of the hand led the way to an infinite line of inventions, of a similar character. This device involved the distinction between the chip and the shaving, between the uncertain and the precise, the slow and the expeditious, and finally in its later developments, between the puny weakness of the human arm and the practically unlimited giant power of machinery. Specifically we confine our attention here to the common planes, leaving alone the vast number of applications of the principle of guidance that are embodied in the tools which are controlled in machines.

The different kinds of planes now made number hundreds.

Almost any form of cutter can be put in a stock, while the shape of the latter can be so modified as to suit work corresponding with the sectional shapes of the cutting irons, as in the moulding planes, and the proportions or relations can be made adjustable, as in the ploughs.

The old woman's tooth, or "router," is used for planing out the bottoms of recesses, the depth to which the iron stands out from the face of the stock being adjustable. It is therefore an exception to the general plane design, in which the iron stands but very slightly out from the face of the stock, $\frac{1}{32}$ inch, $\frac{1}{64}$ inch, or less.

There are so many different kinds of planes that, though they have a family resemblance, the various groups require to be operated differently, if the best results are to be secured. Actually there are only two instances in which a plane iron is employed in the same fashion as a chisel is used in paring—that is, with the

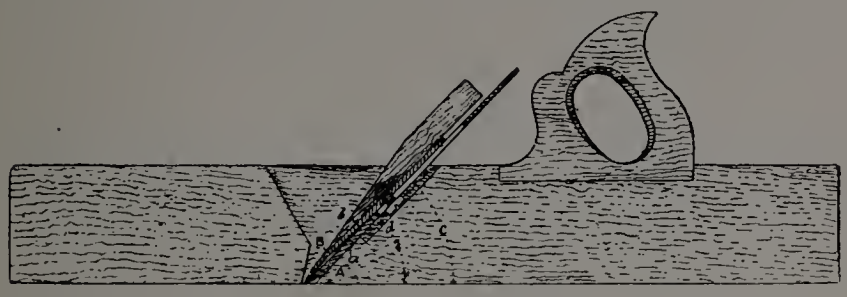


Fig. 38.

flat face in exact coincidence with the face of the work. One of these is the familiar spokeshave, the other is the rounder plane, used for rounding up rulers, broom handles, and other long circular rods, the iron cutting tangentially. In all other cases the chisel is set in its stock, neither parallel nor tangentially, but in such a way that its cutting face makes a large angle with the face of the work. And it does not matter in the least which face lies next the work, whether the flat, or the bevelled one, since the power of control no longer lies with the chisel itself, but is transferred to its stock. The flat face may be downwards, next the stuff, as in many of the iron planes, or it may be uppermost, as is the usual practice. In the first, the angle of setting the chisel in its stock is low, or acute; in the second, it is steep.

The first important point is the secure fastening of the iron, so that it becomes practically one with its stock. It must not rock

in the slightest degree on its seating *a*, Fig. 38, and the wedge must bed closely down at *b*, all over it. In this way the tendency to chattering and vibration is eliminated, and these are the principal causes of choking. Other points are, to see that the corners are removed on the hone, and that the iron is either sharpened straight across, or with the slightest possible convexity, which is tested by standing the edge of the iron lengthwise on the face of the stock, and noting the light underneath. An iron must not be in the slightest degree concave.

When one begins to handle planes, the first trouble that arises is that the shavings choke in the mouth, between the iron and the stock. This is more apparent in the trying, and smoothing plane, than in the jack plane. The first impression is, therefore, that the mouth is too narrow to permit the shavings to get away, and an apprentice will not infrequently, unless checked, cut the mouth wider, and so lose two or three years of wear. But the fact is soon discovered that better results are obtained if the amount of convexity given across the edge of the iron is increased, and thus another error is committed—that of making the irons of trying and smoothing planes nearly as convex as those of the jack plane. Then, of course, they are unfit for producing true surfaces. For if those irons be sharpened straight across, and only just the corners rubbed off, they will operate as freely as though well rounded, provided other matters are attended to.

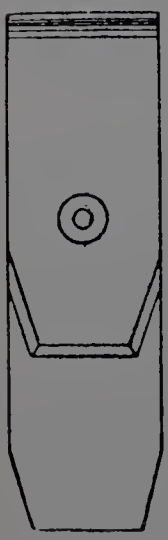


Fig. 39.

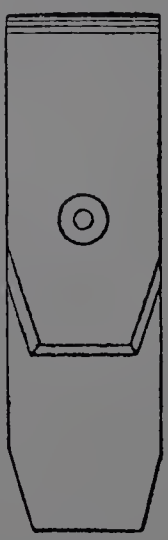


Fig. 40.

The rigidity of the iron A, is increased by the addition of the top iron B. The difference between single and double iron planes is most marked, and this is due largely to the fact that the screwing-down of the top iron tightly on the cutting-iron stiffens the latter so much that all chance of chatter is absorbed thereby. How important this is may be observed by noting the difference in the working of a plane when the top iron is set back from $\frac{1}{16}$ to $\frac{1}{32}$ inch (Fig. 39), and when it is brought down quite close to the cutting edge (Fig. 40). The first is incompatible with

the production of the finest results; the latter is essential thereto. In working on soft pine the coarse setting has scarcely any evil results; but it becomes most marked when attempting to plane crooked grain, knots, and hard, harsh wood, and end-grain, on which it is impossible to produce smooth surfaces except with a finely-set top iron.

The setting of the top iron also has a secondary influence. It coerces the severed shaving immediately behind the cutting edge, and compels it to bend over at the instant of severance. We remarked (p. 23) on the distinction between the axe that cleaves the wood a little way beyond the cutting edge and the paring chisel that removes and cuts up a fine shaving, the first action being percussive, and the second purely cutting. A similar distinction occurs, but in a less marked degree, between the single and the double iron. Take a single-iron jack plane (Fig. 41) set coarsely, and note the kind of shavings removed. They are not curled off regularly, but appear to have been split off in a succession of jerks, the stuff being divided in front of the actual cutting edge. But, using a finely-set double iron (Fig. 42), such an action is not apparent, for the shaving appears to be quite unbroken.

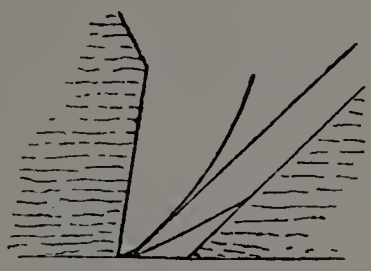


Fig. 41.

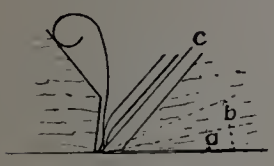


Fig. 42.

Anything that interferes with the perfect controlling action of the top iron lessens the efficiency of the plane. If the bedding of the top iron is not perfect on the other, the plane will choke, or chatter. If its edge is not parallel with the cutting edge the same evils will be induced. Even the greasy dirt that accumulates on the top iron will tend the same way, and it should therefore be rubbed off with glass-paper.

As yet these remarks have had reference only to the good or bad action of those planes which are designed for, and are appropriate to, the class of work upon which they are commonly used. But the question of the appropriateness or otherwise of a plane to its work raises many points of detail. To be concise, the problem may be considered from three points of view—the question of angles, of linear guidance, and of profiles.

The remark has already been made that the sweet working of planes is less a question of angles than of keeping them in good order. Thus the iron of a common plane, Fig. 38, is set at an angle *c*, of 45° in its stock. The ground bevel *d*, makes one of about 20° to 25° or 30°, with the face of the stock, depending on the work of the plane, and when newly ground the sharpening angle *e* is not very sensibly divergent therefrom. Yet the plane continues to work sweetly after successive re-sharpenings until at last the angle will be reduced to 5° or 6°, *f*, with the stock. The only thing that remains constant is the angle of top rake—namely, 45°. Though the cutting angle is always increasing as the plane-iron thickens, and the clearance angle is always being reduced, yet the tool works sweetly. On the other hand, in an iron plane in which the iron is set face downwards at an angle of about 15° with the face of the stock, the clearance never changes; but that of top rake and of cutting always increases with sharpening. And the cutting angle of the latter usually becomes thicker with re-sharpening than is practicable in the case of the irons of the wooden planes, for with a face angle of 15°, and a grinding angle of, say, 20°, if this is gradually increased by 10° to 15° by sharpening, the total angle will be greater than that which is possible in the wooden planes. The foregoing facts, taken as a whole, explain why the same planes can be readily used for the hard and soft woods, unlike the cutting tools for metals, which are generally shaped differently for different metals. But though a 45° of angle in a plane iron is used for both classes of timber, the workman makes slight differences, as experience dictates when working in one or the other. The differences lie chiefly in the degree of setting of the top iron, which is finest for the hardest and harshest woods, and in the coarse or fine setting outwards of the cutting iron, for removing coarse or fine shavings respectively. In the moulding planes a difference is made in angle for hard and soft woods, the irons in the former being set at 55° or 60° instead of 45°. But the forms of these planes are much less favourable to sweet cutting than are those of the bench planes, for reasons which will be noted directly.

The angles of plane irons are compared with the action of the chisel in Figs. 43-45, between which there is much analogy. Shavings are coarse or fine, one difference consisting in the fact that the coarse shavings are broken, while the fine ones are not perceptibly so. If we consider the action of a chisel

when removing coarse and fine parings, we shall see a marked difference. In the first case the parings will be like Fig. 43, broken in polygonal forms; in the second, Fig. 44, they will be continuous, and regularly curved. The same effect is observable in planes, the coarsely set single iron of Fig. 41 breaking up the shaving, the finely set double iron of Fig. 42 removing it as a continuous ribbon. But the iron in Fig. 41, if set ever so finely, would not remove such fine shavings as Fig. 42; neither if the latter were set very coarsely would it chatter so much as the former. Hence, in planes the addition of the top iron is necessary in order to counteract the influence of the angular setting in the stock, which setting being a departure from the chisel principle, tends to cause chattering. An important function of the top iron therefore consists in the diminution of vibration of the cutting iron, effected by increasing the *rigidity* of that portion of the plane. That rigidity is the main essential, rather than the mere breaking of the shaving, is borne out by the fact that iron planes are the

Fig. 43.

Fig. 44.

Fig. 45.

most rigid of all, and that in these, single irons (see Fig. 45) can be used without chatter, or choking, even when cutting against the grain, and on harsh stuff.

In Fig. 42, showing the iron of an ordinary plane, whose face *c*, is set at an angle of 45° with the face of the stock; 45° does not represent the cutting angle, for *a* is the angle of presentment of the tool to the work. It is that included between the narrow sharpened facet of the iron, and the face of the material, ranging between about 5° and 10° only—just an angle of relief, and no more. The other, *b*, is that formed by the first grinding of the basil, and is the reserve, so to speak, which is drawn upon for sharpening. The top face *c*, answers to the bevel therefore of a chisel, and the sharpened facet, or rather the sole of the stock, to its face. In Fig. 45, which represents the mouth of an iron plane in section, the bottom angle *a*, is increased, being about 20°, and the top *b*, on which the sharpening takes place is not very different from that of the first example. But in these apparently

diverse cases, that which renders the plane so valuable is the guidance afforded by the stock, without which it would not be possible to remove shavings of uniform thickness, that is, with chisels alone, held at the same angles as the plane irons.

Our second point—that of linear guidance—is the feature that is most obvious in planes; in all its degrees, from the tiny thumb-plane of 4 in. to 6 in. long, to the cooper's planes, measuring as many feet. In another form we have the planes controllable in sweeps, known as compass planes, the elementary type of which is the spokeshave.

Since the control of the iron depends on the linear guidance exercised by the face of a plane, this is proportionate to the character of the work done. Hence the reasons why the planes which are used for making close joints, whether glued or not, are always the longest. The common jack plane is never employed for this purpose, and its length is limited to from 14 in. to 17 in. But the trying plane ranges between 22 in. and 26 in., and when specially long joints have to be made, jointers are used from 28 in. to 30 in. long, while the cooper's jointer of 5 ft. to 6 ft. is an extreme instance of specialisation. Smoothing planes, rebates, moulding planes in all cases measure less than 12 in. in length, for there is no question of very accurate jointing in most of these—that is, not in the same degree in which it applies to the trying planes.

However accurate the face of a plane, it wears with service, and therefore it is periodically "shot" with a trying plane in good order. Jack, trying, and smoothing planes are treated thus, twice or thrice in a twelvemonth, and every care is taken, by the assistance of straight-edges and winding strips, to restore the faces to perfect accuracy. To maintain permanence of form is the principal reason for the employment, first of iron-soled planes, and then of planes with iron stocks. The latter may be of the skeleton form, or a skeleton may be filled in with blockings of hard wood. But there is the other advantage derived from iron planes, due to their rigidity, and by virtue of which they work more sweetly in hard, harsh, cross-grained, and stringy woods than those having stocks of wood.

The circular, or compass planes, are used for concave sweeps. The simplest form is a smoothing plane with a sole cut convex lengthwise. But such a plane is not well adapted for any sweeps

which are of much flatter radius than the radius of the sole. The next advance is to insert a sliding piece in the front, by the adjustment of which the range of utility is increased. In American forms the sole is made flexible, consisting of a thin strip of elastic steel, which is adjusted to any required curve by means of a thumb-screw. Compass rebate planes are also employed, and in some cases both the face and one side are sweeped.

The third point of view from which we have to consider the planes is that of their profiles, or the sectional forms of their cutting edges. These are the counterparts of the work which they have to do. In the trying plane we have seen that the edge has to be as straight as possible if close joints have to be produced by it. In the jack plane a good deal of convexity (Fig. 46) is imparted to produce a penetrative and shearing cut, in which its primary value lies. But the controlling power and co-relation of the plane to its work is seen in its greatest development in the numerous moulding planes. The labour of cutting a strip of wood into any moulded form by means of chisels and gouges is so great that the development of these planes was an early necessity. Possibly the "hollows" and "rounds" preceded the numerous moulding planes, which are mostly combinations of hollows, rounds, and flats. Though these are superseded in modern shops by the moulding machines, they are yet used in the small country shops, and on jobbing work.

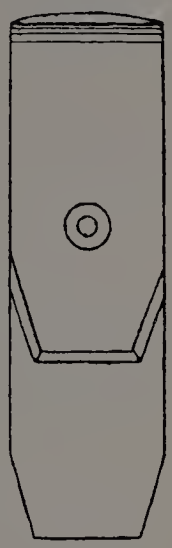


Fig. 46.

Knack is required to handle some of these planes nicely—such as some of the ogees, quirk ovolos, torus, beads, and sashes—because the combinations of curves and flats are such that some portions of the irons are in the worst possible position for cutting—in fact, in some localities they stand perpendicularly to the work instead of at an angle, as all irons should do. To a slight extent this is counteracted in some planes by setting the stock at an angle to the work, or at a "spring," in order to lessen these drawbacks by a principle of averaging. But good working mainly depends on the careful way in which they are sharpened, set, and used. Particular care must be exercised to keep the angles keen enough, and the edge profiles of the iron exactly co-

incident with those of its wooden stock. These planes also suffer from the disadvantage that they have single irons only, and are therefore liable to chatter. For this reason the bedding of the iron on its stock, and the close fitting of the wedge are very important points. The planes are also rather hard to work, and drag somewhat, especially in wide and deep mouldings. Some of these planes, like the plough, are used for cutting deep grooves,

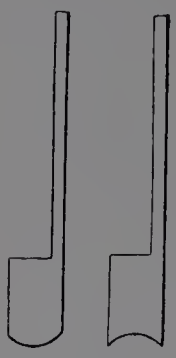


Fig. 47.

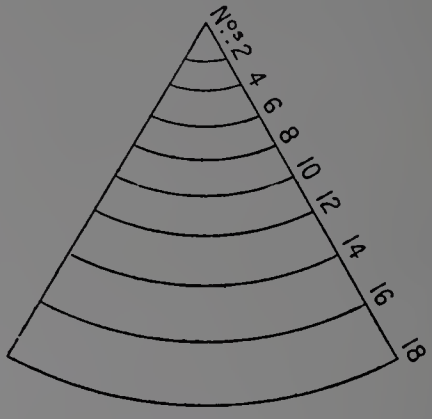


Fig. 48.

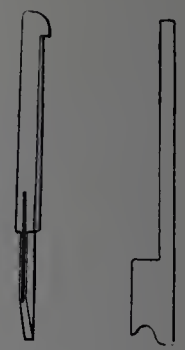


Fig. 49. Fig. 50.

and though perpendicular edges are present, they are not actually cut by the iron, and here friction and dragging occur.

Some of the profiles of these planes are grouped in Figs. 47 to 50. Figs. 47 are the irons of rounds, and hollows, the sections of which, going by numbers, are shown in Fig. 48. Fig. 49 is the iron of the plough for grooving—eight irons of different widths forming a set for a plane. Fig. 50 is the iron of one form of beading plane. Besides these there are planes to correspond with various mouldings for sash bars, and strips, to enumerate which would be hardly possible here. Ovolos, quirk ovolos, ogees, astragals, reeding tools, sash tools, air-tight planes for making tongued and grooved joints, filisters, and others. Rebate planes occur in various types, straight, and skew mouthed (Fig. 51),

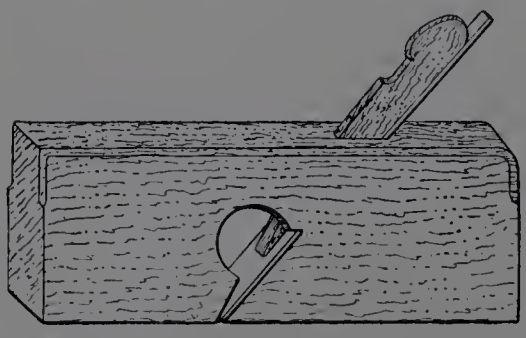


Fig. 51.

and side rebates. Chamfer planes form another group, and so do chariot, and bull-nose planes, for cutting up close to a shoulder.

The iron planes have, to a large extent, invaded the province of those with wooden stocks, some firms making a speciality of their manufacture. They occur in the following groups: jack, trying, and smoothing; the latter being commonly termed block planes;—bull-nose, rebate, circular-soled, tonguing and grooving, routers, hollows, and rounds, beading, ploughs, universal, and spokeshaves.

Fig. 52 shows a lever block plane. The lever A takes the place of the usual wedge. It is pivoted at *a*, and turning the milled head and screw B, pinches it on the top of the iron at *b*. Instead of tapping the iron inwards or outwards, it is moved slightly by the lever C, hinged at *c*, and having serrations on its upper face to engage with serrations on the lower face of the iron at *d*.

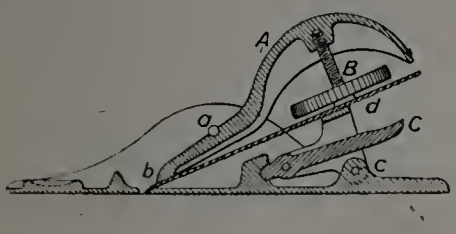


Fig. 52.

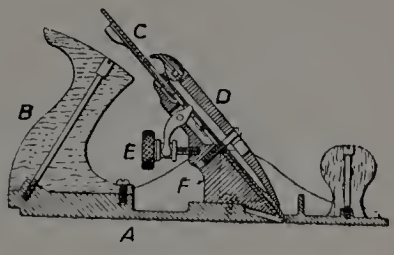


Fig. 53.

A different type of iron plane is shown in Fig. 53. A is the base into which the handle B is screwed. The iron C is double, and the cap D holds the iron down. The adjustment of the latter is effected by the milled head E operating a lever entering into a slot in the iron. The portion F, the frog, can be adjusted to close up the opening of the mouth if wear occurs.

No plane is easily handled by the beginner. The art consists first in exercising the most perfect control over the tool, instead of allowing it to wabble about all over the stuff. It is true that the workman appears to hold it very slackly and easily; but he has, nevertheless, a perfect grip on it, so that it does not tip up at the beginning and termination of every stroke, nor slip over the knots, nor remove shavings from the wrong places.

All planes, except the tiny thumb planes, require to be gripped in both hands. The trying and the jack planes are grasped by their handles with the right hand, while the left is spread over

the top of the body of the plane near the front end, slightly gripping the sides also. The smoothing planes and all the rebates and moulding planes and their cognate forms, which have no handles, are gripped in the rear with the right hand, the heel of the hand exercising a thrust on the stock downwards and forwards, while the left hand steadies the plane in front.

The degree of pressure transferred from the body to a plane varies much, being very considerable when roughing down. Most planing, like sawing, taxes the muscles, though, when accustomed to it, one can occupy a whole day in either task without feeling unusually tired; but it exhausts the beginner. The muscles of the arms, and a portion of the weight of the body are both brought to bear upon the plane, and the proper degree of force exercised is graduated in a nearly unconscious and instinctive manner.

The guidance of the planes usually depends on the skill of

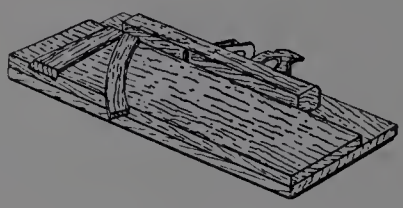


Fig. 54.

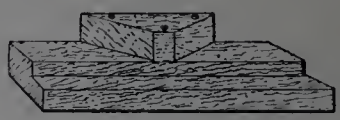


Fig. 55.

the operator. All those in which the edges of the irons lie inside the stock, as in the jack, trying, and smoothing planes, require no control save that of the workman, except when used on a shooting board (Fig. 54), or a mitre board (Fig. 55), for planing edges and ends. But when the irons come out flush with edges, as in the rebates, or when they project, as in the plough, or when a planed edge has to be worked by, as in the beads and kindred forms of moulding planes, they are coerced, either by the edge of a strip of wood tacked upon the face of the work, in the exact position where a shouldered portion is to be formed, as when rebating, or by a fence, which is adjustable, as in the plough, or by a fixed fence, as in the beads, filisters, &c. In planing narrow strips, with rounds, or hollows, the angle board (Fig. 56) coerces the stuff sideways, preventing it from slipping about. The rounds, and hollows, and many others are controlled only by the fingers of the left hand. Tools of

these classes are only suitable for cutting with the grain. Some are used also for cutting across, but then a saw-kerf must be made to sever the grain, as in rebating.

Another point is, that the skilful man does not need to check the results of his work nearly so often, or so much, as one who is unskilled. When planing a level surface, the latter timidly resorts to straight-edge and winding-strips long before the surface is approaching completion; the other feels by the nature of the contact between the plane and the wood how the work is progressing, and uses the edge of the plane itself as a rough straight-edge—tipping the tool to a slight angle, and glancing under the edge in the intervals of every few strokes. And yet he arrives at the desired result quickly. If he has much to slog off, he does not plane in an unvarying, straightforward fashion, but alternates these cuts between cross and diagonal ones, which are of the nature of shearing; so not only reducing material with the minimum of labour, but also getting close

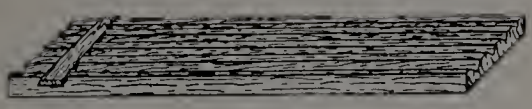


Fig. 56.

approximation to truth across the board. As also the jack plane removes stuff most rapidly, its employment is continued until the fine finishing of the trying plane becomes quite necessary. A beginner will commence working with the trying plane too soon, and so waste time in removing a quantity of material that could have been taken off in one-fourth the time with the jack plane.

Further, with a view to preserve the edges as long as possible, and so avoid the need of too frequent sharpening, the experienced man relieves the cutting-iron of the weight of the plane on its backward stroke, so preventing friction between it and the face of the board. The harsher and more gritty the stuff, the more desirable is this instinctive precaution. Before roughing-down dirty stuff with the jack plane, too, the careful man brushes the outside with card wire, to remove the dirt and grit before using the plane on it, and then he sets the iron coarsely in order to get well beneath the surface in the first cuts, instead of allowing the

dirt to grind the edge off the plane, just as the iron-turner and machinist get below the skin at once.

When testing the truth of planed faces, both straight-edges, and winding-strips are requisitioned. A straight-edge alone will serve the functions of both, because when held diagonally across a board, if the straight-edge shows true faces in both diagonal directions the face is out of winding, the result being the same as though tested with parallel winding-strips at the ends. But this method, though quite suitable for short pieces of stuff, say not exceeding 2 ft. to 3 ft. in length, is not so suitable as the other for long wide boards, because the strips magnify any error due to their length, the latter being considerably longer than the width of a board. Of course, in trying the truth of boards it is not enough to lay the straight-edge on them. That is good enough during the earlier stages, but later, chalk must be rubbed on the straight-edge, and transferred by very slight pressure and slight endlong movement to the face being planed. This visibly indicates by its transference or not, what portions of the face are high or low, and where the material requires removal. The straight-edge is tried crossways at intervals of every few inches, and a long straight-edge is also tried lengthwise; besides which, the winding-strips are tried on. Sighting down the latter, the edge of the farther one is more clearly seen if the face that lies next the edge is whitened with chalk.

Always the first step is to plane one face perfectly true, and gauge the thickness from that by which to plane the second face. As a board is seldom quite straight across when taken from the rack, the concave face is better to begin work on than the convex, because the latter would be pressed down, and sprung by the weight of the plane. But it is always better to "jack" over both sides before beginning to finish either face; or if this can be done a few days, or even a few hours, before planing to thickness, it is better, because there is less risk of the board warping subsequently.

When planing end grain, the expert workman does not let the plane tip over the end and split the stuff out; but he either chamfers the extreme end with a chisel, or else planes a few strokes from each end alternately, relieving the plane just as it comes to the termination of its cut. When practicable, he will plane ends and edges on the shooting-board (Fig. 54, p. 48), rather

than in the vice, because with the use of the shooting-board there is no necessity to try the truth of the edge with the square, relatively to the face of the board.

A good workman will not allow one plane to usurp the functions of another, nor expect the smoothing plane to produce a true surface like the trying plane, nor use the latter merely to dress off joints flush, or to clean a dirty surface previous to glass-papering, or to round-up an edge. Nor will he attempt to round-up any considerable quantity of work with a smoothing plane when hollow planes are available.

To set an iron in its stock suitably for different classes of work is not quite so easy as it appears. Beginners knock their planes about sadly in getting the irons in and out, and in correcting their setting. No very hard blows need ever be dealt. The most trying work to a plane is the presence of hard knots in soft wood—those in spruce, for example; and contact with these will often cause a loosely fitting iron to start backwards, so that in such cases the wedge should be driven more tightly than under normal conditions; but to drive a wedge habitually tight only springs the stock, without holding the iron any better.

The setting of an iron is accomplished by bringing the face of the plane in line with the eye in a good light, and sighting down, when the exact projection of the iron beyond the face of the stock is readily detected by the eye, and also whether it is parallel crossways. If it projects to a greater distance towards one side than the other, the edge of the iron beside the wedge is tapped with the hammer on the side where the projection is too full. If it stands out too far all across, the top of the plane stock is lightly tapped with the hammer, in jack and trying planes, to start the iron upwards by reaction. In the smoothing and moulding planes, the rear end is struck. A tap on the top end of the iron sets it out. When adjustments are all completed, a final tap or two is given on the wedge.

Damage to planes is caused by the hammering of the stock to effect the removal of the iron. In trying, and jack planes, this is done on the top front face with the hammer held in the right hand, the left grasping the side of the plane, and the thumb being inserted in the hollow of the wedge, to steady it, and control the results. In smoothing planes a sharp blow is delivered at the hinder end; in the moulding planes under the knob of the

wedge. As these blows are repeated so frequently, they must be delivered quite flat and dead, in order not to bruise and damage the wood overmuch. A little knob is often glued into a centre-bit hole in the top of jack and trying planes to receive these blows. When wedges are being driven in, they should not be bruised and burred over; partly with a view to prevent this, their edges are chamfered.

To maintain planes in good order, fit for producing clean and smooth surfaces on soft straight-grained woods, is not so difficult as when they have to work against the grain, and over knots, and on stringy harsh stuff. In some of these cases it is better to have an iron sharpened rather thickly than thin, and it will usually have to be set very finely to remove a mere scrape; in fact, in such cases the plane, though sharp, will do better if its action approximates to scraping, because it will not then have so great a tendency to tear up the harsh, coarse grain. When planing sappy stuff the mouth is very liable to choke, and the tool works with much friction. A liberal application of sweet oil to the sole of the plane is very helpful in this case.

In sharpening moulding planes much care is necessary in order to preserve their profiles exactly. The irons should be ground on very small emery wheels, or they are filed sometimes with new finely-cut files; they are sharpened with gouge slips. In using any of these planes it is difficult to start properly. Some, like the sash filisters, have adjustable guides or fences to be held against the side of the work. So have the beads, the ploughs, the chamfer planes, and others. In the rounds, and hollows the workman's hands afford the only control. In the rebate planes it is usual to nail or clamp a strip down to the work as a guide. In depth gauging there are stops, as those used for sash filisters and for the ploughs, and these are adjustable with screws, so that we get a good many complications in moulding planes. But in a large degree interest in these has diminished since mouldings are stuck by machinery, and there are many younger joiners who have never had a chance to use such planes, and have had no need to add them to their kit.

The wear and tear of planes is due to the wearing of the iron, of the sole, and of the removal, and resetting of the iron. The first-named has the effect, in most cases, of increasing the width of the mouth, the exception being in the case of those irons which

are parallel. In the tapered iron, the wearing-down, due to regrinding, brings the thinner portion down to the mouth, and so increases the width of the latter. But the chief wear to planes is that due to the constant friction of the face, which causes it to get out of truth, to correct which the face has to be "shot," or planed afresh, so widening the mouth. After several years this width becomes so great that a mouth-piece has to be fitted across.

In selecting planes, the grain of the wood is a matter of much importance. Straight grain of course is looked for; and heart wood must be rejected. A hard quality of timber, cut from the outer layers of the tree, is the best; the latter being apparent by the ring segments having scarcely any convexity. The silver grain also must run perpendicularly to the face of the plane, and not diagonally. A stock selected thus has the best wearing quality, and is less liable to warp than one in which the contrary conditions are present.

All plane stocks are made of beech, excepting the smallest thumb planes, and spokeshaves, and the quirks, and fences of some of the moulding planes, ploughs, &c., which being subject to much wear are of box. To preserve a new plane, a good plan is to harden its face by saturating it for two or three days in raw linseed oil, and rubbing oil all over elsewhere, applying it thickly and afresh as it sinks into the grain. Also after shooting a plane, the face must be saturated with oil to harden it, and to cause it to work more sweetly.

CHAPTER IV.

Hand Chisels and Allied Forms for Metal Working.

The Cold Chisel—Cutting Angles—Shape—Breadth—Method of Use—The Cross-cut Chisel—Diamond Point—Cold and Hot Setts—and Gouges—Setts for the Steam Hammer—Nicking Chisel—Drifts or Broaches.

THESE chisels are not nearly so numerous as those of the wood worker. They are simple in character, and yet a very slight difference, not to be appreciated save by those who know them well, will make all the difference in their effective, or non-effective action. The roughing-out tool *par excellence* of the fitter, is the cold chisel in its various types. The cutting edge of the typical "chipping" or "cold" chisel (Fig. 57, A) gives 60°

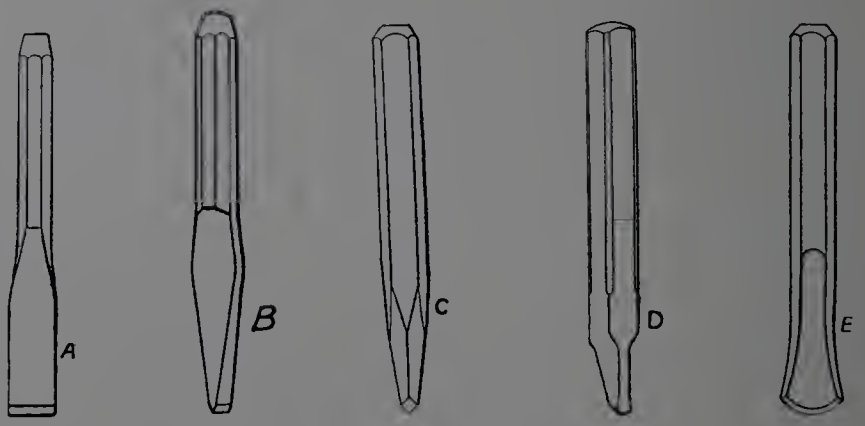


Fig. 57.

cutting angle, but it may, and does vary several degrees on each side of this, not only for different materials, but for materials of the same character. The practical rule to lay down is, that the harder the material, the more obtuse the cutting angle; the softer the material, the more acute will it be. This of course is a necessary modification, not alone in the case of chisels, but also of all cutting tools, not because an obtuse edge cuts better than an acute one, but simply because it endures better.

A little practice soon demonstrates the best angle for a chisel for any particular kind, or grade of metal. Hard, harsh metal will rapidly spoil the chisel edge, and then the remedy is obvious—grind it thicker. But a moderately thin chisel will cut soft iron rapidly, and without losing its edge, and one thinner still will work gun metal, and brass with ease. This is really the ultimate test, the cutting of the largest quantity of any given material with the least expenditure of labour, and the most lasting permanence of edge.

The tool is held approximately at the angle in which one facet comes nearly parallel with the face of the material being operated upon, giving the smallest possible angle of relief. A slight rounding is imparted to the edge in the transverse direction, the object of which is to prevent risk of the corners catching in the material, which would draw the chisel out of parallel. Most wide chisels are ground thus more or less rounding, though sometimes straight, but never hollow; not much rounding, however, is given, else the chipped surface would present a series of furrows.

The breadth of the chisel has an influence upon its action. For steel, and wrought iron, a narrow chisel is preferable to a wide one, because they are of a close solid texture, and require a considerable application of force to effect the removal of chips therefrom. But the more crystalline cast iron and brass are more suitably attacked with wider chisels, which have less tendency to dig in, and to tear up the material than the narrower ones. This again is not a hard-and-fast rule, since both wide and narrow chisels are used indiscriminately on all grades of metal. But the principle laid down is nevertheless a correct one. A good deal will depend on the force of the blows, the depth of cut, and the amount of material attempted to be removed.

To use the chisel, hold it near its head in order to afford steadiness of grasp, stand in an easy, unconstrained posture, not hugging the chisel too closely, and deliver the blows from the shoulder. The cutting edge of the chisel is to be kept pressed against the cut, and the surface is to be reduced as evenly as possible, to lessen the subsequent labour of the file. Finishing cuts will be taken with quicker and lighter blows than the roughing cuts.

When reducing a surface of large area, the labour can be lessened, and better results obtained by first cross-cutting the

surface all over with the cape, or cross-cut chisel (Fig. 57, B). A series of narrow grooves parallel with each other is cut with this over the surface, and the material removed from between with the ordinary chisel. The same chisel is used as a "sett" for nicking pipes, or plates preparatory to severance.

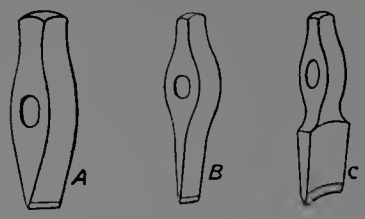


Fig. 58.

The economic importance of chipping has considerably diminished in the workshops during the present generation, owing to the wider employment of planing, shaping, and milling machines. There is, comparatively speaking, little call now for skill in chipping, except in the case of repairs, and of work too bulky to be put under the machines. To many, therefore, the chipping and filing of a large surface true, especially if that surface be awkardly situated, as for instance a slide valve face enclosed within the sides of its steam chest, presents a not too easy task.

Fig. 57, C, is a diamond point, one of the setts, used for nicking metal which has to be severed, and also for cutting grooves. Its resemblance to the vee chisels of the carver (p. 33) will be apparent, the difference between the two being one of thick, and thin cutting angles. Fig. 57, D, is a narrow round nose, also one of the setts, corresponding with the wood-worker's gouge; while Fig. 57, E, is a wider gouge, concave on the face, also termed a cow-mouthed chisel.

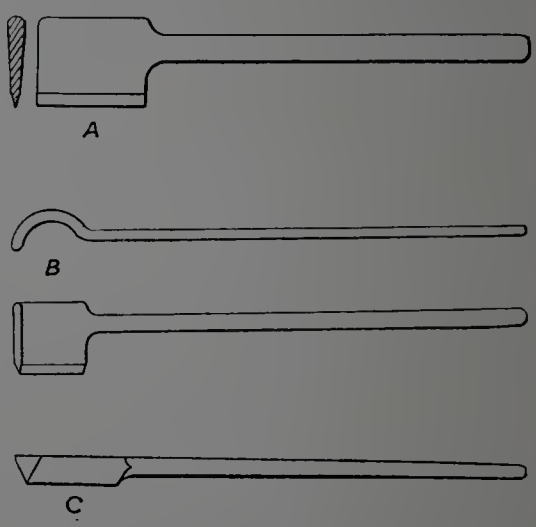


Fig. 59.

These tools are used in several metal-working trades, by fitters chiefly, but also by smiths, and boilermakers, on forgings and plated work, as well as on castings.

The next group is for forged, and plated work, the cold and hot chisels or setts being held to the work, and struck with sledges.

Fig. 58, A, is the cold, and Fig. 58, B, the hot sett, the difference between the two being that of angle only, the latter being thinner than the former. A would entail unnecessary labour in severing hot metal, while B would not retain its edge long in cold metal. Fig. 58, C, is the gouge, or hollow sett, made also for hot and cold metal, and in various curvatures, and singly as well as doubly bevelled. These are handled with rigid rods of ash.

The next group fulfils similar functions, but they are used chiefly with power hammer work. Fig. 59, A, is a sett made thick, and thin, for cold, and hot metal. Fig. 59, B, is a hot gouge sett handled like the previous one. Its function is severing or dressing ends which are to be bossed, instead of cutting facets to produce polygonal outlines.

Fig. 60.

Fig. 59, C, is a very obtuse-angled chisel which operates as a nicker only, setting in round a rod under the hammer preparatory to severance. It is used on hot, or cold bars.

Drifts are true chisels. Some operate by their ends only, but most are serrated (Fig. 60). They both cut, and shear, and are used to finish holes that have been roughed out with drills, or chisels. They are employed both in blind, and thoroughfare holes, finishing accurately and to uniform dimensions. They are used by hand, or in a machine. In America they are termed broaches.

CHAPTER V.

Chisel-like Tools for Cutting Metal by Turning, Planing, &c.

Roughing and Finishing Type—Roughing Tools—Finishing Tools—Parting Tools—Inside Tools—Tools for Planer and Shaper—Cranking—Overhang—Stiffness of Tool and Support—Roughing and Finishing Tools—Straightforward Tools—Cranked Tools—Broad Finishing—Slotting Tools.

THE principal types of these tools are shown in Figs. 61 to 65. They are mainly divisible in two groups—roughing, and finishing. On some kinds of work there is but one type practicable—the finishing, which combines the two functions. The angles of tools that operate on the same materials are varied according to whether they are employed for removing material in quantity, or for finishing by scraping. In the latter case they have little or no top rake, the top face being normal, or nearly so, to the surface of the work. It is also essential to the highest smoothness of finish that the edge be broad, and straight. The angles of scraping tools are nearly alike for all metals and alloys, differing in this respect from the roughing tools.

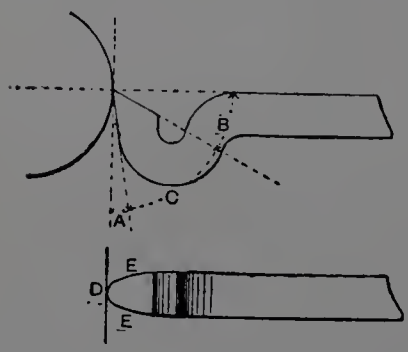


Fig. 61.

Fig. 61 is the commonest kind of roughing tool for lathe, planer, or shaper, and if clamped in a bar, for the slotting machine also. A tool used for the same work is prismatic in form, instead of being round-nosed, being slightly easier to grind. As a rule, to which there are numerous exceptions, the roughing tools are round-nosed, the advantage being that they possess penetrative capacity in a large degree. And because the correct cutting angle only occurs at that portion of the tool D, which

projects most, and in a diminishing degree round the curve, until at E E there would be no top rake at all, this limits the useful work done when deep cutting is attempted, and explains the advantage possessed by right and left handed roughing tools, in which the point of highest projection and greatest rake corresponds with that portion of the work being cut where the penetration is deepest. Four such tools are shown in Fig. 62, in pairs. The right, and left hand tools at A differ from straightforward ones in the method of grinding the top rake—top side rake in these cases. Those at B differ in being bent round, the grinding of the top faces being then normal to the centre line of

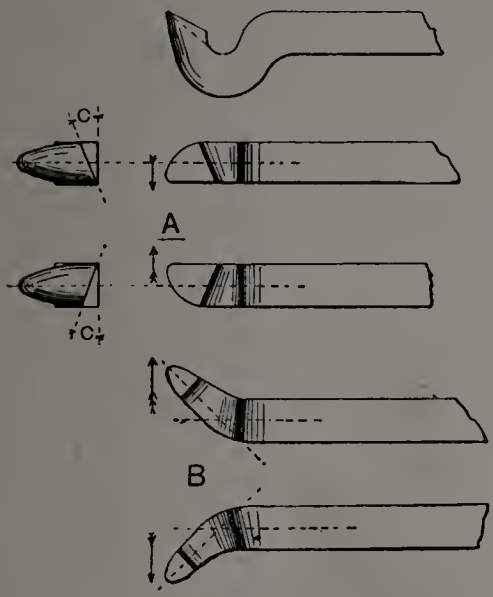


Fig. 62.

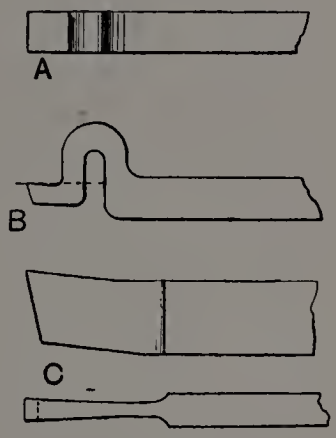


Fig. 63.

the bent part. The arrows indicate the direction of movement of the tools, and C C shows the direction of the top side rake.

Fig. 63, A, shows a broad finishing tool in plan, which is used with coarse sliding feeds, but only for removing shallow chips. The amount of top rake in these is variable, but is generally slight, ranging from zero to 10° or 15°. Fig. 63, B, is the spring tool, used for fine finishing, with a mere scrape. The action of this tool can be better understood by a reference to the planer tool (Fig. 64), the point of which is brought back somewhere about in line with the back of the tool shank, in order to prevent risk of the cutting edge digging in, in consequence of the spring of the planer rail, or of the overhanging of the end of the tool. But

for the inconvenience of the arrangement, it would be better to mount the planer tool behind, instead of several inches in front of the rail. With the tool shaped as in Fig. 64, it cannot dig in, even though it should spring back, because the point would be immediately thrown off the work. For the same reason a turning tool should not be set above the centre of the work, but level, as in Fig. 61. So, too, if the spring tool, Fig. 63, B, meets with an obstacle, it yields, and will not dig in. The cut becomes analogous to a drawing cut, as distinguished from a pushing cut. But spring tools are not suitable for working to fine-gauged dimensions; they simply impart a smooth finish, serviceable in work of an average character.

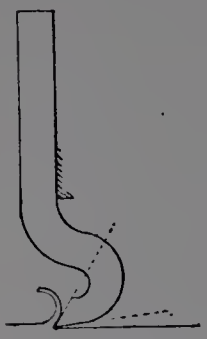


Fig. 64.

Tools for parting off (Fig. 63, C) have clearance both behind and below. Being generally very thin at the cutting end, this is commonly reduced from a bar of greater width, in order to afford sufficient width and rigidity for clamping in the tool-holder. Such tools are also in some cases required to be right and left handed. The same tool generally serves for roughing and finishing, but knife-edge or side tools (Fig. 65, A), right and left handed, straightforward, as shown, or bent, are used for facing an end, following the parting tool before a piece is actually cut off, as in facing the ends of spindles. As the metal removed by the parting tool is slight, and leaves little room for the knife tool, the latter is therefore made narrow and nearly pointed. The same kind of tool is also much used in turret lathes for turning down bars, using a very deep cut and a fine traverse feed. Tools having their cutting edges corresponding with the contour of portions of the work are made to requirements. The commonest are the convex and concave shapes, in various radii.

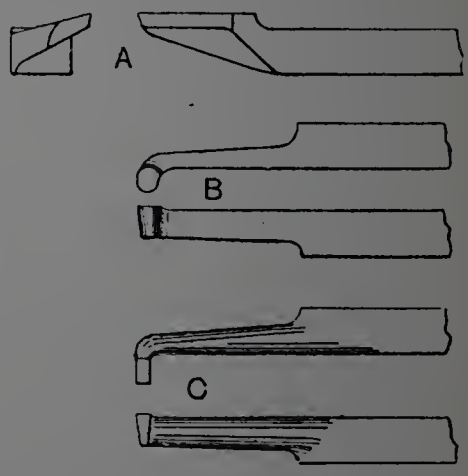


Fig. 65.

Inside tools resemble in the main those used for outside turning, comprising roughing, which can be fed inwards or out-

wards for roughing (Fig. 65, B), or for finishing, or for parting off (C). Besides this, there are the internal screw-threading tools for vee, or square threads, which are like Fig. 65, C, but suitably shaped and ground at the cutting end; and those for worms of the sectional form in Fig. 66, the clearances of which have to be regulated according to the slope of the thread to be cut.

Fig. 66.

The question of the best forms of tools to use on planing and shaping machines is complicated by the conditions under which the tools are used. Thus results depend on overhang, and depth of cut nearly or quite as much as on correct formation. The typical roughing tool occurs indifferently in all forms, very much cranked (Fig. 64), or scarcely cranked at all (Figs. 67 and 68). The first is theoretically correct, the second incorrect, yet both work well under suitable conditions. The essential difference between the two is this, that under given conditions Fig. 64 will not dig into the work, or chatter, and Figs. 67 and 68 will.

But the latter are used more extensively than the former, and the reasons for this seeming contradiction are not obscure. In the first place, solid tools are made of steel ranging from, say, $\frac{3}{4}$ in. square to 2 in. square, depending on the nature of the work which they are designed to do, and they are, therefore, very rigid under ordinary conditions of duty. Another matter is that the machinist invariably endeavours to give the least amount of overhang possible to the tool, by bringing the tool-box as close to the work as the conditions of the work will permit of. In this way the spring of the tool is reduced to a practically unappreciable amount. So that in Fig. 68, if the edge of the tool-box is brought to the line *c*—*d*, the heaviest cutting can be performed without the tool-point digging into the work, or breaking off. *c*—*d* would be possible in the majority of cases, *a*—*b* being exceptionally high up.

Figs. 67 and 68 represent the roughing tools commonly used on planer and shaper for cast and wrought metals respectively. The differences are that the first is broader at the cutting point, and that the cutting-angle is greater than that in the second. Cast metals, being more crystalline, do not offer so great resistance to the tool as wrought metals, nor is so much heat generated during cutting. So that broader cuts are, as a rule, practicable with the former than with the latter. Experience has also demonstrated

the necessity for making a difference in the cutting angles for cast and wrought metals. Usually a difference of about 10° is made, the tools for wrought metals being the keener. The difference is made on the top or cutting face, there being no necessity to make any in the clearance angle. Often, however, though not necessary, there is such a difference made, the clearance angle being slightly greater in the tools for wrought than in those for cast metals. Though the term "cast metals," is employed, brass, and gun-metal are excepted. The tool commonly used for these is shown in Fig. 69. There is no front rake, and the clearance angle is in practice very variable, often being much greater than that indicated. The resistance to cutting is so slight, that a large clearance angle is possible without seriously affecting the durability of the tool point. But brass and gun-metal are very com-

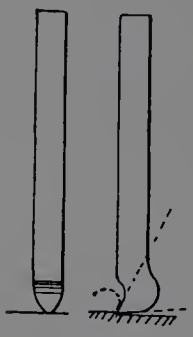


Fig. 67.

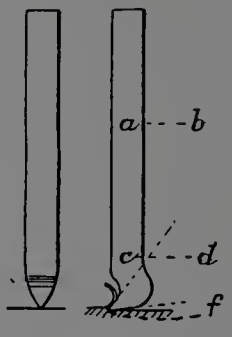


Fig. 68.

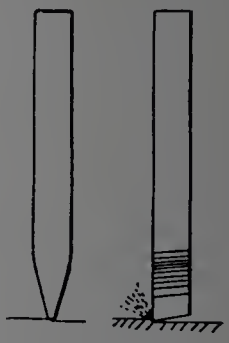


Fig. 69.

monly planed, and shaped with the same tools that are employed for cast iron and steel, both for light and heavy cutting. If the tools are stiff, and held firmly, there is no perceptible tendency to "draw in," or to chatter apparent.

The three forms illustrated in Figs. 67, 68, and 69, are the types upon which numerous cutting tools used in planer and shaper are based. Each of these is of the straightforward class—that is, it is usually presented perpendicularly, or normal to the surface of the work, and the traverse feed takes place at right angles with the tool shank. But these forms of tools, and methods of presentation by no means cover the whole range of work which has to be done. Since the surfaces which have to be machined in planer or shaper occur in many positions, they necessitate correspondingly varied methods of presentation of the tools. It is always desirable to machine the whole, or as large a portion of

a job at one setting as possible, because the risk of error due to inaccurate subsequent setting is prevented. The swivel tool-boxes permit of a great deal of variation in methods of presentation of tools. But, apart from this, it is often necessary to use tools cranked to right, or left hand, and both roughing, and finishing tools occur in these forms. The reason is that it is frequently not possible to set a tool at an angle in the tool-box, as, for example, when it has to pass down between adjacent vertical parts to plane some portions which are undercut, or which lie at an angle. The following figures illustrate the principal forms, shown operating on surfaces of work typical of those for which they are generally best adapted.

In Fig. 70, A and B illustrate the application of a straight-

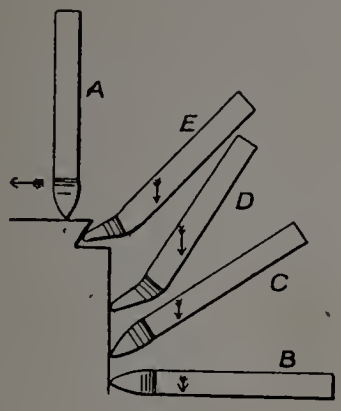


Fig. 70.

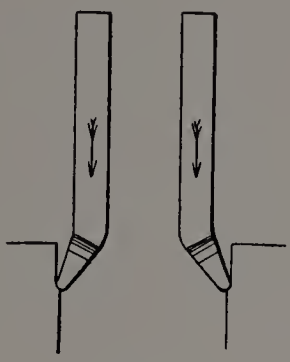


Fig. 71.

forward tool in the two positions in which it can be used most favourably. A is the position suitable for horizontal surfaces, and this is how the bulk of planing and shaping is done. B represents it as on vertical surfaces. But the method of presentation shown at B is only possible when there is a supplementary tool-box on one of the vertical sides of the planing machine, or on a supplementary standard by the side. And it is not possible at all to use it so on the shaper, so that many vertical faces have to be planed with a tool set diagonally, as at C or D. C is not of a form quite so favourable to cutting in this direction as D, though both are employed indiscriminately. It would be a troublesome job to cut down an angular face except with a cranked tool, as indicated at E. And for cutting down vertical faces in confined positions in which there is no room to set the tools at an angle, as in Fig. 71,

the use of cranked tools is absolutely necessary to the production of accurate results. The straightforward and cranked tools, therefore, each being kept in forms suitably ground for cast, and wrought metals, constitute the most extensive equipment of planing and shaping machines.

The tool grooves left on the surface of the work are always visible as distinct grooves, but so shallow that the surface is sufficiently accurate for very many purposes. For a large quantity of work, the practice is to take two cuts with the same roughing tool; the first with a deep cut, and coarse feed, which leaves the surface much ridged or grooved, and the second with a shallow cut, and fine feed, which reduces the work to the finished dimensions required, and leaves the tool marks visible, but scarcely perceptible to the touch as distinct ridges. For the finest work, however, this is neither true enough, nor is it finished sufficiently. Then the broad-finishing, or broad-cutting, tool (Fig. 72) is employed. The depth of cut effected with this is almost imperceptible—a mere surface cutting, or scraping of fine shavings or dust—but the traverse feed is large. From a $\frac{1}{4}$ in. to $\frac{3}{8}$ in. is a common amount of traverse for average work; but on large surfaces $\frac{3}{4}$ in. or 1 in. is often given, and in some cases even this is exceeded. The width of tool is greater than the feed imparted to it, say, $\frac{1}{8}$ in. more at least, and the extreme corners are rubbed off on a hone. The marks of these tools remain visible on the surface of the finished work, corresponding in width with amount of feed given. It is to remove these, and to impart a still higher degree of accuracy, that scraping is resorted to. But for all except the highest class of work broad finishing is practically true, unless, indeed, the machine slides, or the mode of setting the work produces inaccuracy.

These are the typical tools, but others of varied forms are derived from them, the difference being in outlines, and not in cutting, and other angles. It is not necessary to illustrate all these, since tools are frequently devised for special jobs of work. Thus, broad-cutting tools like Fig. 72 are commonly made right, and left handed for side cutting, or cutting at angles, similarly to the roughing tools in Figs. 70, 71. Tools of similar type, straightforward, are used for cutting or finishing grooves, as in Fig. 73. Round-nosed tools of various radii are also used in planer and shaper; while for recesses, cranked tools are employed.

There are three movements of planer and shaper tools, and each has various rates, depending on quality of metal, condition, and shape of the tools used, and the nature of the cutting being done. The movements are the travel, or forward movement of the tool, or of the work; the cutting feed, or depth to which the tool penetrates in a single cutting movement; and the traverse feed, or width of cut taken by the tool during a single cutting or return movement.

The rate of forward movement varies from about 15 ft. to 40 ft. per minute respectively in the case of the hardest materials, and heavy cuts; and of the softer materials, and lighter cuts. 20 ft. a minute is a good average speed for cutting cast iron. The maximum speed for cutting wrought iron with a single tool is about 40 ft. per minute; a very usual rate is 30 ft. But so much depends

Fig. 72.

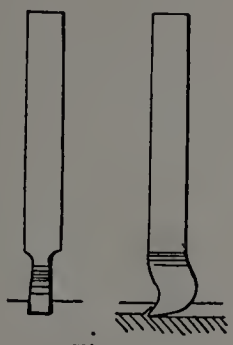


Fig. 73.

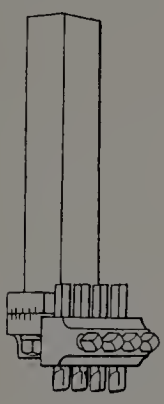


Fig. 74.

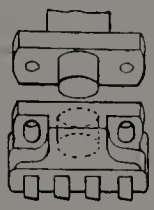


Fig. 75.

on feed, depth of cut, and quality of metal, that those are simply averages. Using high speed steels for tools, these rates are easily trebled. The cutting feed or depth of cut varies from an almost unappreciable amount up to $\frac{3}{8}$ in. and $\frac{1}{2}$ in. deep. The traverse feed or width of cut varies from, say, $\frac{1}{64}$ in. to 1 in., or more, in broad cutting, or finishing cuts.

The Armstrong "gang" planing tool (Figs. 74 and 75) comprises a holder carrying four tools, each successive tool being set laterally a little in advance of the preceding one. Each therefore cuts deeper than its predecessor, and the result is that a greater aggregate amount of cut is taken than would be possible with a single tool point. The advantage of this is very apparent on large surfaces, which are thus planed more quickly than in the ordinary way. The holder comprises a shank, upon which the

tool head is fitted with a projecting stud. Two set screws, passing through slots in the head, attach it firmly to the shank, while allowing of circular swivelling taking place. This latter provides the means for setting the tools in successively deeper, the swivel of the holder being graduated, so that an exact and known amount of swivel can be imparted. This slewing naturally alters the side clearance of the tools somewhat, but the amount is insufficient to be noticeable. The diagram, Fig. 76, shows the effect of this, the left hand side cutting deeply, and so having less clearance than the one on the right, which is cutting finely and therefore has not been swivelled so much in the holder. The arrow shows the direction of motion of the planer table.

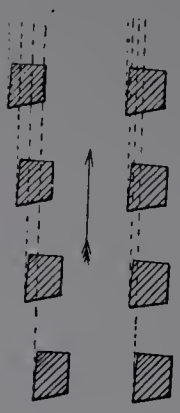


Fig. 76.

In the slotting machine, no feed whatever can be given to the tool. In this respect it differs from both planer and shaper. All feeds are imparted to the table on which the work is bolted. Heavy feeds can be utilised, because the cutting force passes mainly through the longitudinal axis of the tool, which is in line with the ram, and the latter is always massive, and moves in long slides. The tool always tends to spring backwards under the stress of cutting; but this is diminished by using a stiff shank, and reducing the amount of its projection to a minimum for each job. To permit of this, the height of the ram above the table is rendered adjustable. For some work, a tool like a planer tool is used, and set at right angles with the axis of the ram (Fig. 78); but it is mostly employed when the ordinary straightforward type is not suitable. An objection to the usual form of tool is that it cannot be lifted clear of the work during the up, or non-cutting stroke. Arrangements for lifting the tool have been devised, but are not to be seen on one out of a hundred machines. In practice, the friction during the up stroke is not very detrimental, because the cutting-edge is not ground acutely, and does not soon suffer. Neither have tool-holders met with much favour in slotting machines, notwithstanding that there are one or two good ones offered for sale.

A few useful solid slotting tools are grouped together in Figs. 77 and 78. In the first three figures the tool is shown in side elevation, and in inverted plan—that is, the bottom figures repre-

sent the cutting edges looked at from below. In each instance the cutting point or edge is to the left hand. In Fig. 77 the first tool to the left is of the diamond point type, and is used both for fine cutting, and for finishing right into the corners of angular work. The second and third are round-nosed tools, used for roughing out, and also for finishing concave work. The fourth, seen in side and front views, is a common tool, used both for roughing, and finishing, and generally for completing work at one cut, and specially for key-way grooving, being tapered backwards from the cutting edge.

Fig. 77.

Although the essential forms of the tools used on slotting machines are not numerous, yet each occurs in so many dimensions, that the total numbers run up rapidly. There may very well be 15 or 16 key-waying tools at a machine, all of precisely the same form, but of different widths. And so of other tools. Hence the equipment of an ordinary slotting machine will run up to 70, 80, or 100 separate tools. There are two ways in which the amount of metal in slotting tools is reduced. One is by making the tools double-ended—a very common practice—as in the key-grooving tool to the right of Fig. 77. The other is by using several detachable tool points in one shank, as seen in side and front views to the left of Fig. 78. The latter has other advantages besides the economy of metal; it often saves time—the time occupied in changing and setting the solid tools. It also furnishes the lighter tools with a substantial shank, by which they are enabled to operate more steadily and sweetly than if forged on a solid shank of light proportions. In one example the tool point is held with one, or with both of the set screws shown; in the other a wedge only is used.

Two tools are often used at one time for cutting either on external or internal surfaces, an example being a horn block for a locomotive, which is machined for the vertical movements of the axle-boxes. A single block only, or two or more, are often

superimposed and machined at once. The tools are not only clamped, but a stretcher of hard wood is inserted to keep them from being sprung inwards through the stress of cutting. The reason is that the manner in which the tools are set deprives them of the support of the face of the ram during cutting, and the pinching of the clips might not be sufficient to prevent springing or working back of the tools. There are many jobs where the inner faces which have to be slotted are situated too closely to-

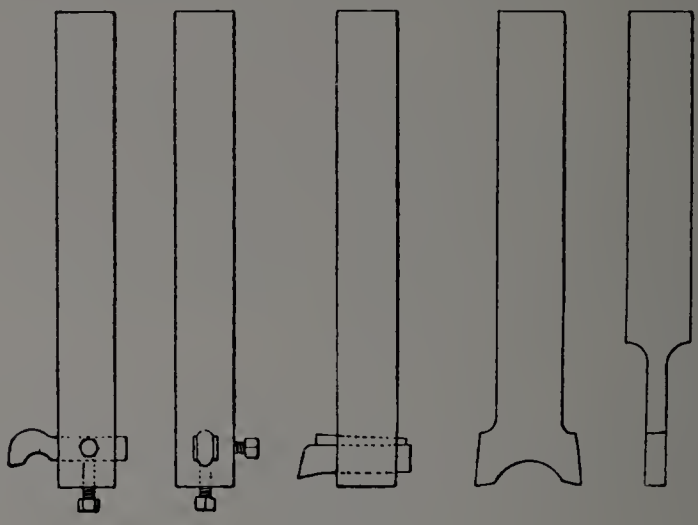


Fig. 78.

gether to permit of the convenient employment of two separate tools. To avoid the waste of time involved in the use of a single tool operating in succession on the two faces, one formed like that to the right of Fig. 78 in front and edge views is used, when the number of pieces to be slotted will permit of the cost of making such a special tool. The width of the tool is precisely the same as the finished width between the faces of the bosses, and there is but one cut taken over them. The hollow is simply imparted for facility of grinding the cutting faces.

CHAPTER VI.

The Shearing Action, and Shearing Tools.

Shearing, a detailed operation—Diagonal Cutting with Chisel—Fox Trimmer—Square and Skew mouthed Rebate Plane—Turning Chisel—Reamers and Milling Cutters—Roughing Tools—Walker Planer Tool—Profiled Tools—Shear Blades—Necessity for Support to the substance being Shorn—Staggered Cutting in Mills—Flat Drill—Combination of Shearing with Staggering.

THE labour involved in cutting hard materials is so great that various devices are adopted in order to lessen it as far as practicable. One of these is to remove the shavings or chips by a detailed action—a successive, but unbroken method of cutting, which is termed shearing; the other is similar in its results, though different in its operation, and embodies an action that breaks up the continuity of the chips. In a few instances the two devices are combined—namely, the shearing, and the staggering cut.

The first is applied in the case of tools operated both by hand, and by machine, on timber, and on metal. When great resistance is offered to cutting with a chisel, the hand instinctively slides it along diagonally, and so applies the muscular effort to greater advantage. It comes more naturally on hard, than on soft wood, for it is nearly impossible to take a fair cut across the end grain of the hard woods, if a chisel is actuated straightforward. The labour of planing straightforward over a considerable width is great, being evident in the work of a coarsely set trying plane. As an extreme case take the power planing machines. A common panel planer, having parallel knives, say 24 in. in length, will absorb something like 3 H.P., and then will pull up its engine if forced to take exceptionally deep cuts.

One of the most useful of the modern tools in the pattern shop, and joinery is the Fox trimmer, and its great value lies in

the nature of its shearing cutting. The blades A A, Fig. 79, are screwed to their backing at an angle of 45°. Being actuated by a long lever, pinion, and rack, they are slid longitudinally for right, and left handed cutting. The work rests on the table B, and adjustable wings at the ends permit of setting the work either square across, or to any angle. The trimmer shears off thick or thin chips at one traverse across the entire area of an end presented to it, and with perfect truth, and as clean as though planed, due mainly to the shearing action of the blades.

Since the shearing cut produces a clean surface, that affords another reason why it is sometimes adopted in preference to the straightforward cut. The difference is very marked—for example, in a square-mouthed rebate plane working across coarse grain in soft wood, and a skew-mouthed one. The latter not only operates with less labour, but it cuts much more sweetly, taking off curling

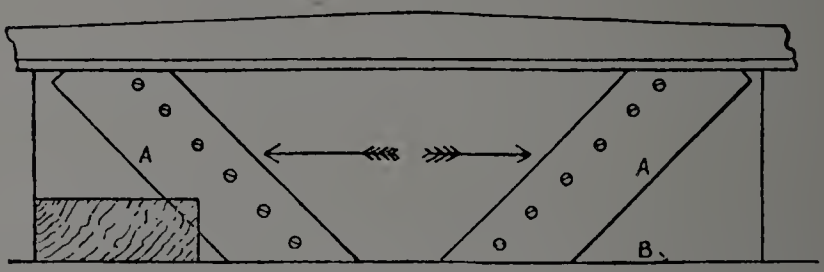


Fig. 79.

shavings, and leaving a sleek, polished surface. Or plane a rebate lengthwise with the two types of planes; and not only will the labour required in the first be bound to be greater, but the surface which is cut will not be left so smooth, for a slight chatter will be found to have left its marks in places.

Examples of this kind might be multiplied, but one more may suffice—the turning chisel. The action here is always that of shearing; the scraping chisels are not in the running for removing material rapidly, or for leaving clean, smooth surfaces.

The difference which we note in the rebate planes, and in turning and scraping chisels is perfectly paralleled in the edge types of reamers and milling cutters. Few of these of over an inch in width have their teeth set parallel with the axis, but they are placed at an angle therewith (see Fig. 117, p. 99), to take a series of shearing cuts. The tendency to chatter is thus lessened,

and the cut surface is left smooth. It is partly due to their shearing action that these cutters, with little or no top rake, act so efficiently. Latterly the tendency has been to increase this in amount, until on mills of considerable length the spiral twist becomes very marked. In some few mills the angle is found to measure as much as 50° with the axis of the cutter. Fig. 118, on p. 99, illustrates a French cutter, and some of the Pratt & Whitney mills have angles as great. Again, in built-up mills each separate piece is often set with its teeth in the opposite direction to that one adjacent (Fig. 119, p. 99). Each shears, but the endlong stress of one is counteracted by that of the other. By such devices work of from 24 in. to 30 in. in width is tooled readily.

When the action of most metal-cutting tools is considered, few are found in which the action of the shearing cut does not occur, and this, without regarding those which are commonly known as shearing tools. Even the common roughing tools act partly by shearing, since sloping sides and edges take a share in cutting. The entire absence of such an action in parting-off tools, and in broad finishing tools, whether straight, or curved in profile, explains why they are so hard to operate, and so liable to chatter. A familiar example of the shearing cut occurs in the knife tools used for facing ends. These are often bevelled so that the edges slope. The same formation is adopted in some roughing tools of the knife class used in turret lathes.

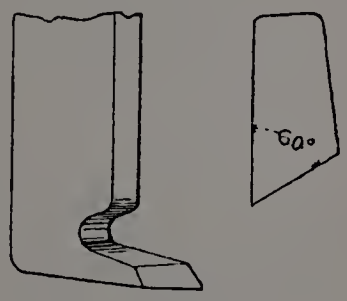


Fig 80.

The Walker planer tool shown in Fig. 80, is designed for taking broad finishing cuts. Its value lies in its shearing action, which not only renders the cutting easy, but prevents the breaking out of the metal at the edges of iron castings. The angle of the slope—namely 60°—is seen in plan.

Amongst the most remarkable tools of recent years are those of the forming type, used for brass finishers' work. Whatever the shape of a brass casting, provided it admits of turning a profile, a tool can be made to the profile, and slid tangentially thereto, cutting and finishing over the whole breadth at one traverse, and producing any number of pieces all exactly alike. One of these tools is shown in Fig. 81, with the piece of work it is designed to finish

beneath. The tools are milled to the section required, and never lose their form, because they are ground at the end only. The end is bevelled to an angle of 30°, and it is remarkable how very sweetly the cutting action is performed, as the cutter goes gradually through its work. There is no limit to the sectional shapes that can be formed in this way, and one movement of a lever is all that the attendant has to give to operate the tool.

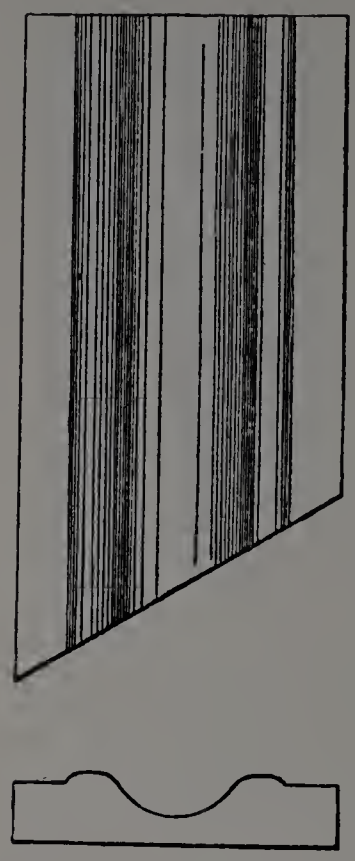


Fig. 81.

The shearing cut, therefore, is a power in the rapid removal of metal, just as it is in the side chisel for wood, and in the diagonal movement of the common chisel, instinctively imparted when paring the end of a piece of timber. Just as it is also in the skew-mouthed rebate plane, and in the little spill plane, which shears off the curling shavings that wrap tightly round it into a conical spill, with which to light your pipe.

Without the diagonal cut, the majority of the shearing tools would be nearly inoperative. Only by their gradual action (see the diagram, Fig. 82, which represents the angles of a pair of shear-blades) can they be made to sever materials. It would be clearly impossible with any amount of power to close, say, the 4 ft. blade of a shearing-machine instantly on a thick plate without damaging the blade, and plate. The question of tool angles here seems to be of much less importance than that of the thickness of plate shorn, and of the degree of support afforded to it. There is no parallel between the removal of a shaving of metal with a cutting tool, and the separation of a mass of metal

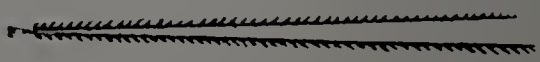


Fig. 82.

through a considerable thickness. A shaving is curled off or broken immediately it is severed, but a plate in course of severance is backed up and rigidly supported by the mass of metal behind. Hence the action of the tool is only slightly cutting, and more largely squeezing—detrusive, a violent forcing of the material apart—and in a plane parallel with the faces of the shears.

The diagonal severance occurs in the common scissors, and garden shears, sheep shears, and allied tools, though in a much reduced degree. The humble lawn mower is fitted with shear blades. The diagonal punch, Fig. 230, p. 160, embodies the same principle.

It is essential to the successful operation of all the shearing class of tools that the work be properly supported between the blades, or between the edge, and a bolster. If there is an open space between which the work can become squeezed, it will be bent, and distorted (see Fig. 83, A). What is seen to happen in loosely-jointed scissors would also occur in engineers' shears if the blades were not in opposition in the plane of cutting (Fig. 83, B). But instead of the metal getting squeezed between, it would be bent somewhat at the severed edges and distorted, and the work of the shears would be interfered with, and increased by reason of the want of adequate support, and would probably become blocked and injured.

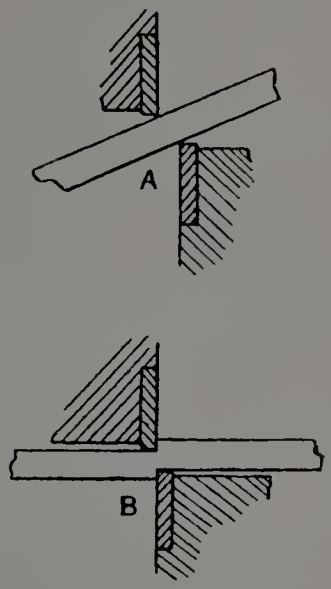


Fig. 83.

The staggering of teeth is variously done. Fig. 154, p. 117, illustrates a common practice. Mills are built up thus on the hit-and-miss style, so that the teeth shall come into action in quick succession, instead of continuously, along a considerable length. The penetrative power is increased, and wide profile work is tooled with comparative ease.

Fig. 199, p. 143, is another illustration of staggering, seen in the flat drill used in screw-machines for roughing-out a tapered hole rapidly. This is followed by the smooth tapered reamer in Fig. 200, p. 143.

The last advance to be noted is the combined shearing and

staggering of cutting edges, by which their penetrative power is still further increased, and in this way wide work is milled with increase in depth of cut. Either the mill is formed in the usual way by cutting the spirals on a universal machine, and the length of a spiral is broken up into short teeth subsequently, or the separate teeth are inserted into the body of the mill in diagonal lines. In each the effect is practically the same. In some cases the mill is made hollow, so that the teeth shall be flooded with lubricant during cutting.

SECTION II.

SCRAPING TOOLS.

CHAPTER VII.

Examples of Scraping Tools.

The Nature of the Operation—The Metal Worker's Scrape—Some Wood-Turner's Finishing Tools—Arboring Tools—Fly Cutters.

SCRAPING tools form a large group, and they are also of much importance, because many tools occur on the border line, where it is often difficult to classify them either as cutting or scraping.

Scraping is an operation which is not incisive, that is, the wedge formation of the tool is absent, and therefore practically it has no penetrative power, and cannot remove either shavings, or chips.

A scraping tool used in lathe, or planer is usually held and operated with its axis normally to the surface of the work. But a hand scrape is generally held at an angle therewith.

Scrapes are used only as corrective tools for fine processes, since they cannot remove material in quantity, but only in the form of dust, or minute particles. But their great value lies mainly in the minute precision of results attainable by their use, and in a lesser degree in the fact that they can be used on very hard material, which incisive tools will not touch.

The scraping tools include the following :—

Those used by metal-workers, in lathe, planer, and other machine tools ; those employed by wood-turners, the toothing plane of the cabinetmaker, for preparing veneering surfaces for gluing, the scrape made of a bit of broken saw blade for smoothing planed surfaces, preparatory to glasspapering, the scrape of the

metal-worker, employed either as a corrective tool, or for fine frosting.

The common scrape of the metal-worker is shown in its more usual form in Fig. 84. It is pushed forward in short strokes, while held at a low angle with the face of the work. The cabinetmaker's scrape is held a few degrees over from the perpendicular.

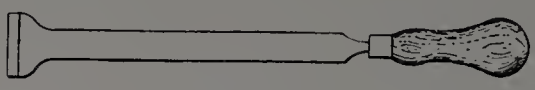


Fig. 84.

Figs. 85 illustrate tools used by wood-turners, which act purely by scraping. They are the round nose A, the right, and left hand

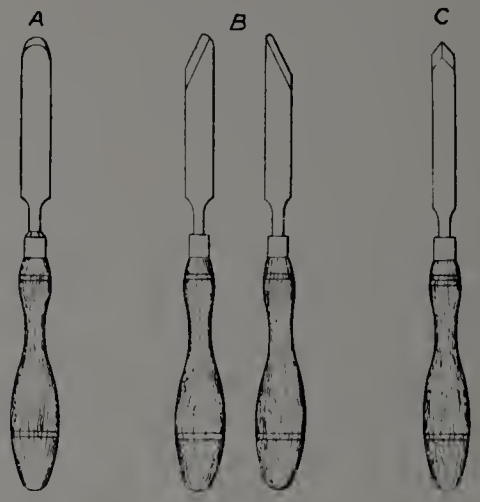


Fig. 85.

side tools B, and the diamond point C, which is a union of the two forms B. The firmer chisel is also used as a scrape by the wood-

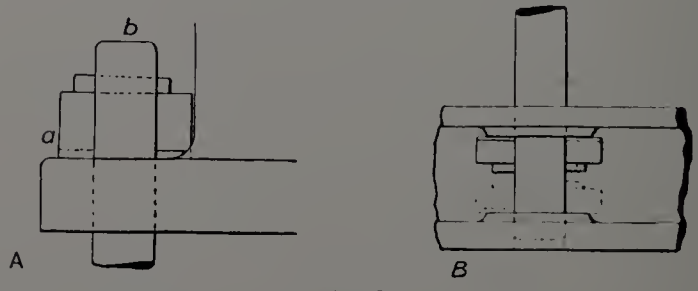


Fig. 86.

turner. The metal-turner employs scrapes in the form of finishing tools for all metals and alloys, including straight-edged tools, and

those with convex and concave edges, parting tools, and others (see Chap. V.). Many facing tools are purely scrapes.

Figs. 86 illustrate facing tools which act by scraping only. Fig. 86, A, is used for cutting faces on the inner side of cylinder covers, &c., to receive the bolts. The cutter *a* is wedged in the arbor *b*, which just fits the drilled bolt hole. In Fig. 86, B, a cutter is shown operating in turn on inside faces of bosses. Fig. 87 is a hand facing arbor, in which the cutter A is fed to its work by tightening the nut B. It is rotated by a wrench on the square neck C. Other examples of facing cutters are given in Chap. XII., p. 127.

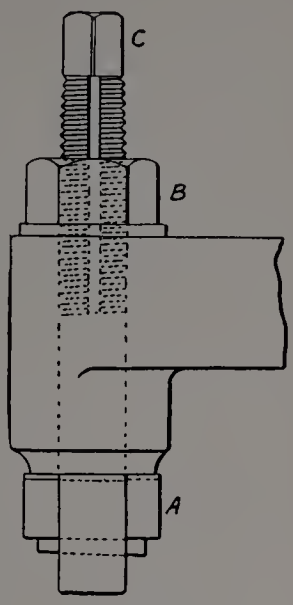


Fig. 87.

Another type of scraping tool is the fly cutter (Fig. 88), used to a moderate extent in some light operations, notably that of cutting wheel teeth of small dimensions, and the teeth of mortise wheels. Its advantage lies in the ease with which profiles can be produced without the trouble and expense of making a complete circular cutter.

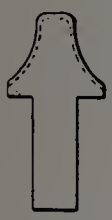


Fig. 88.

It is necessary to distinguish between the scrape, and the cutting tool, otherwise one is apt sometimes to confound the two. These, with the shearing action, are often all represented in the groups of tools to be noticed in subsequent chapters.

SECTION III.

TOOLS RELATED TO BOTH CHISELS AND SCRAPES.

CHAPTER VIII.

Saws.

Wide Scope of the Subject—Saw Teeth, Scrapes and Chisels—Shapes varied to suit Materials—Examples—Spacing—Types of Saws—Reciprocating—Continuous—Variations in Speeds—Tension of Blades—Thickness of Blades—Stiffening of Blades—Back Saws—Wear of Teeth—Degree of Set—Keeping Saws in Order—Set—Its Amount and Regularity—Methods of Setting—by Bending—by Hammering—Test of—Sharpening Saws—Topping the Teeth—by Stoning—by Filing—Files for sharpening—Angles for Filing—Gulleting—The Use of Saws—Forcing—Buckle—Packing—The Place of Coarse and Fine Teeth—Holding Work—Cutting to a Line.

THE points to be considered in the economical working of saws would never be remotely realised, apart from a considerable experience in their use. Are they scrapes, or chisels? What is the reason of the vast differences which exist in the shapes of their teeth, in their spacing, and their degree of set? Neither of these admit of a reply which would not be open to some criticism. And the devices for keeping these teeth in order, and maintaining them in full efficiency, admit of much discussion and differences of opinion.

It will assist us in understanding the action of saws if we consider each tooth as a distinct tool. It will then be apparent that the teeth of all saws, except cross-cuts and those used for metal, are chisels, and mostly, too, with shearing action included. The cross-cut tears the fibres, the ripping does not, but each tooth severs a minute particle of the wood. The cross-cut operates in both directions, the ripping saws in one direction only. The hardness, soft-

ness, or stringiness of the wood also govern the forms of teeth, apart from that of their scraping, or cutting action. Thus, the shapes of saw teeth used for ripping, rake in various degrees, a selection of which is given in Figs. 89, 107, 108, those having the more obtuse angles being used for hard, and stringy, and knotty stuff, and those with acute angles for soft, clean materials. On these leading forms the changes are rung in various degrees, in various shades of difference.

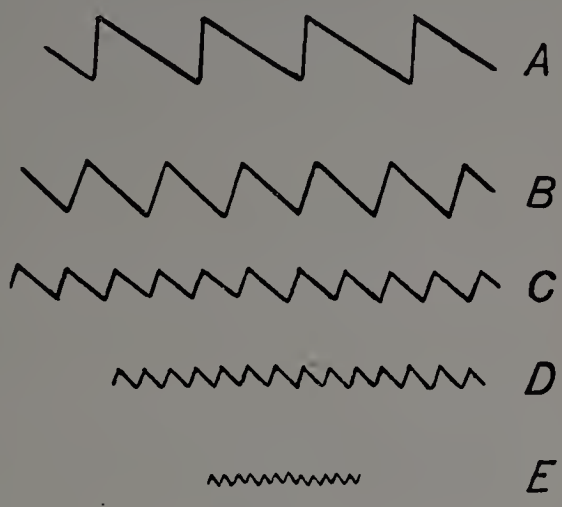


Fig. 89.

A rip, or half-rip saw is the proper tool for cutting down thick planking of soft wood *with* the grain, and it has the least amount of set of any saw, proportional to its size, of course. But a saw having smaller teeth, called distinctively a "hand-saw" (Fig. 90), is that in commonest use, and is generally used as a "cross-cut," that is, for cutting planks, and boards across the fibres, and then it contains the greatest amount of set, and most of all for soft, wet woods. Fig. 89, A, shows the teeth of a rip saw to full size; Fig. 89, B, that of a half-rip; and C that of a hand-saw for cross-cutting.

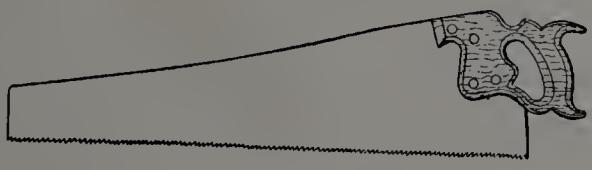


Fig. 90.

Below, at D and E, are shown the teeth of a tenon, and a dovetail saw. A rip contains about two and a half teeth to the inch, a half-rip three and a half, a hand-saw four and a half to five and a half, a panel saw seven or more, a tenon saw ten, a dovetail saw sixteen to twenty.

The degrees of coarseness and fineness in saws are also expressed in "points." The number of "points" is one more

than the number of teeth in the inch; an 8 point saw has but seven teeth. This is the American style.

The type of tooth shown in Fig. 89, but with either more or less hook, and triangular, or gulleted, is universal in all saws that have to cut in one direction, such as ripping, hand, panel, tenon, dovetail, band, and circular. But when a saw has to cut alternately in two directions, as the cross-cut, the teeth are formed differently. The common hand-saw, set especially for

Fig. 91.

cross-cutting, is an exception. Cross-cut saws are generally two-handled, so that two men can operate them; short ones, however, are made one-handled, and as they cut in both directions, equal pressure is exercised both ways, whereas with a hand, or tenon saw the workman instinctively relieves the weight of the saw from the cut on the back stroke, and bears harder on the forward or cutting one.

It follows that a saw cutting both ways must be a compromise in respect to the shape and method of action of the teeth.

Fig. 92.

In a cross-cut saw the typical teeth are shaped as equilateral triangles, with the slopes equal on both sides (Fig. 91). That is how most English cross-cuts have been made for generations. But these are open to two objections: first that the retreating faces of the teeth are not favourable to good cutting action—the rake of the teeth being 30° back from the perpendicular, and second that there is little room for the sawdust to get clear of the teeth. Both faults are much more objectionable in soft

stringy woods than in hard powdery stuff. The M teeth (Fig. 92), in their various modifications, are designed to obviate these evils. This is an old form that fell into disuse in England, was revived in America, and is now sold extensively here. It is modified in several ways, both in the shapes of the M teeth, and in their alternation with teeth of other forms.

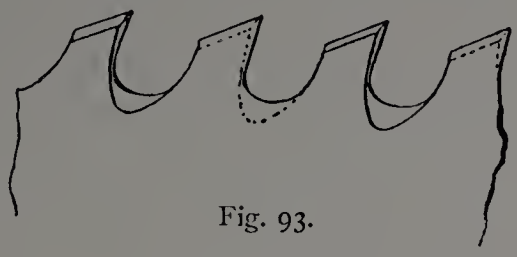


Fig. 93.

Gulleting (Fig. 93) is an important feature in the teeth of saws working regularly in soft woods, as giving more clearance to the dust. It is especially applied to circular saws, which are most rapid in action, and to pit saws. Gulleting is much more important in saws running at high speeds than in other types. Hence circular saws generally have their teeth thus, and the larger the saw, and coarser the teeth, the deeper is the gulleting.

The spacing of saw teeth is a matter of more importance than

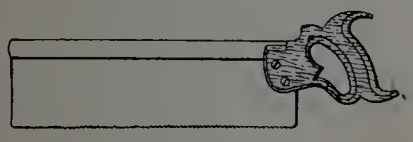


Fig. 94.

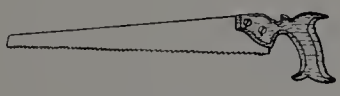


Fig. 95.

it might seem to be on first thoughts. The case is one that has its parallel in the pitch of milling cutters. These were formerly pitched too finely, which caused the cuttings to choke, just as wood dust will choke the teeth of a saw having small spacings. But there is no universal rule for this, since some woods choke more quickly than others. Yellow pine, for instance, will work better with more spacing than stringy spruce will require.

Fig. 96.

There are four broad types of saws—the reciprocating, the circular, the band, and the cylindrical. The latter is restricted to surgical operations on the cranium.

The reciprocating saws include all hand (Fig. 90), back (Fig. 94), and turning, or sweep-cutting saws (Figs. 95 and 96), including the bow saws, the frame or gang saws, the fret saws, or

jiggers, used for sweep-cutting, the hack saws, pit saws, and the cross-cuts. The circulars include but one class, though varied immensely in size, forms of teeth, precise functions, and arrangements, and including those both for operating on metal, and wood. The band or ribbon saws are continuous in action, like the circulars, and like those, are used for metal and timber. They are made in widths ranging from about $\frac{1}{4}$ in. to 6 in., or 8 in.

In all the reciprocating saws except the cross-cuts, the back stroke is lost, as is that of the metal planer, shaper, and slotter among machine tools. But in the circular and band saws the cutting proceeds uninterruptedly, as does that of the lathe, the milling cutter, and the grinding-wheel.

As too there are certain speeds in lathe, milling machine, and grinder, which, though varying with the materials cut, are nearly constant for the same kinds, so there are certain best speeds for continuously cutting saws. Saws are not run at the same speeds for all woods, any more than lathe tools, milling cutters, and grinding wheels are. They can be run too slowly, or too fast; in either case the teeth get dull. In the first instance they lose their edges by mere friction, in the second by friction also; but in both cases the point is that the proper amount of dust is not removed in proportion to the speed of the saws, and the wear upon the teeth. There is waste involved in one case as there is in the other. An experienced saw hand will avoid both, by ascertaining the best rates, meaning the most efficient ones, for different materials, after which the thing is to feed regularly. The metal-cutting saws operate at a high speed in the thin-bladed "hot iron saws," and very slowly in the thick-bladed "cold iron saws."

Other important differences in saws are those which arise from their tension, from the amount of support afforded to their blades, and from the direction in which they are operated.

If a saw is thrust to its work, and nothing but the natural rigidity of the plate is utilised, then the latter cannot be so thin as when the opposite conditions exist. But a thin plate is always more economical than a thick one, because it causes less waste in dust, and this is a very important point where large quantities of material are being converted, as in sawmills. A thin blade also takes less power to operate it, hence one reason of the workman's preference for a thin hand-saw.

Thin blades are stiffened in various ways, in different kinds of saws. One is to strain them tightly, as in frame, or gang saws, in which case the tendency to bend under thrust is taken up by the tension of the blades. In the band saws, rigidity is secured by straining them over their pulleys with a weight, or spring. Another method is to fit a back to the blade, as in tenon (Fig. 94), and dovetail saws, hence termed back saws, the only objection to which is that the blade cannot pass right through, and into stuff thicker than its own depth, and is therefore unsuitable for cutting down boards. In the hand-saws, cross-cuts, turning-saws, and circulars, rigidity is obtained by thickening the blades sufficiently, but making them no thicker than is actually necessary, and as a thick blade works heavily, and is productive of much friction, this is lessened by reducing the thickness from the cutting edges backwards, or in the circular saws, from circumference to centre.

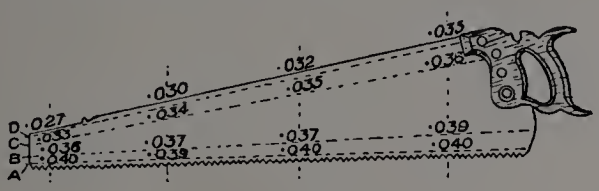


Fig. 97.

The grinding of a saw blade is an important matter, the ease and rapidity of working depending very much on this. The thickness of the blade must taper back from the teeth towards the back, and also from the end towards the handle. Fig. 97 shows the varying thicknesses under this system, the measurements being indicated at various locations, A, B, C, D. The measurements were taken by Messrs Chas. Strelinger & Co. with a micrometer caliper, and are given as representative of a high grade saw.

Saws, as supplied by the makers, are generally sent suitable for a given class of timber. But repeated re-sharpenings, in the case of circular saws, make the teeth, or the tooth spaces smaller, because the same number of teeth remain around a reduced diameter. Then it is better to use the saws for some other kind of work. Or, every alternative tooth can be knocked out, or ground out.

The degree of set of saw teeth varies from almost nothing, in the case of saws used for ripping in dry, hard woods, to larger

amounts in those cutting soft, wet logs, and in most that are used for cross-cutting. No rule can be laid down, but varying amounts of set are given, and saws selected for the duties which they have to perform.

Saw teeth are kept in order by re-sharpening, and re-setting, and here good tools often get spoiled. Minute inaccuracies affect the working of saws, and these become cumulative. Slight variations in the sizes of the teeth do not matter, though they look unsightly, but minute differences in their heights, and in the amount of their set soon show themselves in bad work.

There may be little apparent difference between a saw that works well and one that does not. A sharp tool may work badly, for no saw will cut sweetly if the set is irregular, no matter how sharp it is. On the regularity and the amount of this the best

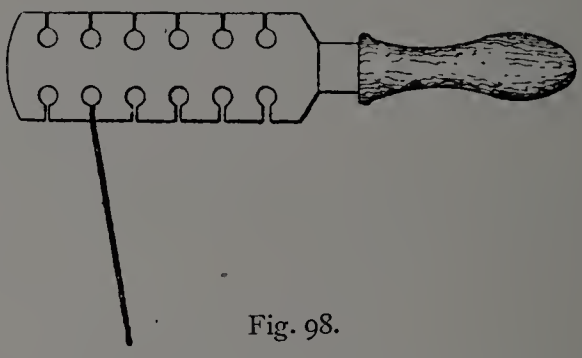


Fig. 98.

results depend. Badly set saws cannot be prevented from hitching in the stuff, and this evil is more pronounced in cutting across, than with the grain, and in cutting harsh and hard woods than straight-grained soft kinds.

The amount of set which is imparted to teeth is varied to suit different conditions. In a tool used for general service an average is struck. But two saws at least are required when regular work is being performed—one for ripping with the grain, and one for cross-cutting. Another may be well added for cross-cutting very wet and thick wood; this one having the maximum amount of set.

Irregular setting is of two kinds: in one it is variable from tooth to tooth; in the other it is in excess all on one side, and insufficient all on the other, though regular for each one side. Both are common errors. The effect of the first is to throw more work on the high teeth than on the others, and dull them sooner.

The effect of the second is to cause the saw to "run" sideways in the direction of the largest amount of set. This, in fact, is sometimes done purposely, when the blade of a circular saw is permanently buckled, in order to counteract the effect of the latter.

Fig. 99.

Setting is done either by the hammer and set-block, or with a bending appliance. Besides these there are some special articles sold for the purpose. A professional saw-sharpener almost invariably employs the first named, an amateur and many workmen the second. The strong objection to the latter (Fig. 98 showing one of the commonest types) is that it is impossible to regulate the amount for each separate tooth with exact precision by bending it with the set. Much practice is necessary to handle this so as to produce a fair approximation to uniformity in the teeth, unless a sliding guide is used. Another objection is that the setting is done by a gradual bending of the tooth, instead of a sharp deflection, starting from the root. Using the hammer (Fig. 99), these evils are avoided. The saw blade being held in one hand at an angle which must not vary materially, the setting of the teeth, each by a single sharp hammer-blow, will be practically uniform (Fig. 100), and the bending will start sharply from the root. The whole of the setting down one side—*i.e.*, of every alternate tooth—is done first, and then that of the other side, both to save time and secure uniformity of results.

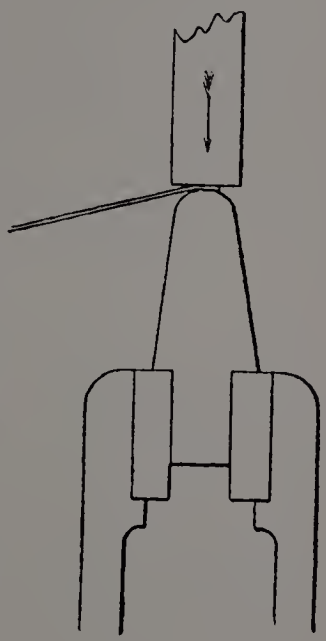


Fig. 100.

Another method which is often practised for fine-toothed tenon, and dovetail saws, is to lay the blade flat on a block of hard wood, end grain up, and set the teeth with a common brad punch; the wood yields sufficiently to allow the teeth to take their set, and without the slightest elasticity, the latter being a frequent cause of fracture when bending with a saw-set. Although the block affords no guide for the amount of set imparted, it becomes easy to regulate the force of each blow with sufficient uniformity to produce uniform setting.

Another plan is to bevel the edge of a block of iron, and lay the saw on it, with the teeth just over the bevelled edge, and strike the teeth with a setting hammer. This ensures uniformity. A single square block may have its four edges bevelled differently, to suit saws having different degrees of set, and height of tooth.

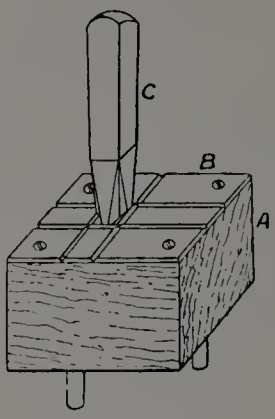


Fig. 101.

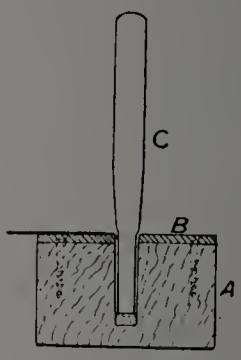


Fig. 102.

Another device is shown in Figs. 101 and 102, where A is a block of hard wood, B a plate of steel grooved for four different sets, &c.; C a steel punch dropping loosely into a hole, in the bottom of which is an indiarubber cube, which keeps the punch just above the saw teeth, which cube, however, yields readily to the pressure of the punch when it is tapped smartly with a hammer. The punch is brought down on the saw teeth, instead of the hammer direct, an advantage which is apparent to those who have experienced how a falsely directed blow will knock two consecutive teeth, instead of alternate ones, in the same direction. Here the tooth is brought close under the punch before the latter is struck, so that it is impossible to mistake one's aim. The four faces of the punch being bevelled to correspond with their

respective set angles, and being duly proportioned in size for larger or smaller saws, simply bend the teeth without thinning them down at the points, and are capable of setting band saws, hand-saws, small circular, panel, and tenon saws.

For those who are afraid to trust to the eye and hand in exact setting, there are various handy devices and tools made, one only of which need be noticed, the Morrill saw set (Fig. 103). Pressure on the handle A pushes the plunger B against the tooth, and the spring pulls it back again on the release of the hand. The amount of set to be imparted is adjusted by the anvil C, which can be moved up and down by its screw. The chief advantage of the set shown is the uniformity of its results.

Fig. 103.

The test of regular setting is to hold the saw, end-on to the eye, and on casting the latter down the teeth, it will be readily seen whether any of them stand out beyond the rest. A more accurate test is to lay a fine needle in the groove formed by the laying over of the teeth, and incline the saw. If the needle runs down, the set is pretty regular; if not, some teeth block the way.

Before sharpening saws, the teeth are topped, circular saws by stoning, other kinds by filing. The stone—any piece of hard material, as millstone, or pennant—is held in the hands before the revolving saw, and brought in contact with the tips. No more is taken off than just suffices to reduce the highest teeth to the level of the lowest. The reduced teeth will be left with little bright facets, which are the guides to which filing has to be done.

In hand-saws, pit, frame, and cross-cut saws, a file is used, a three-square file, or a flat gulleting file, passed down the teeth, or in the direction of hook, a few times, until the topping is complete. There is just the slight risk of the file canting over, and taking more off the teeth on the one side than on the other. To prevent this a file can be mounted and kept for this work—Fig.

104), A being the file, B a packing piece, the file being too hard to drill for screws, C the screws for pinching A and B on the block D, of about $1\frac{1}{4}$ in. square, by 6 in. or 8 in. long. The vertical face lies against the plate of the saw.

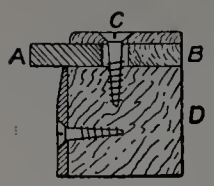


Fig. 104.

With regard to the height of teeth, it is obvious that the case is like that of milling cutters, uniformity in height of which is essential if all the teeth are to be operative. If they are irregular, and one-fourth of the number are below the rest, they will be doing only a part of their work, or be absolutely idle, according to the depth of cut. In frame saws, hand-saws, and cross-cuts, this is just as true as in circulars.

The forms of the various teeth involve differences in sharpening them. The triangular, or three-square file can only be used properly on those teeth the adjacent faces of which make angles of 60° with each other. For other teeth the various mill-saw files are provided.

Fig. 105.

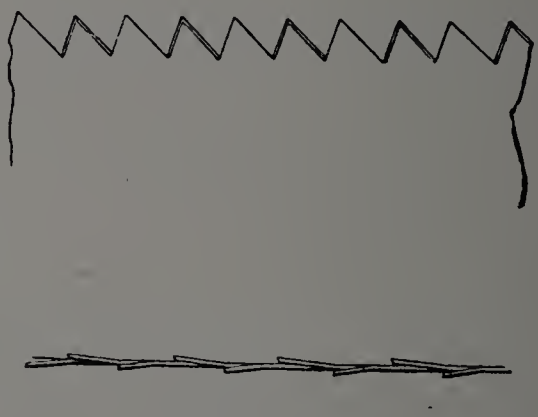


Fig. 106.

The files used are tapered, and parallel, single, and double cut, according to the work they have to do. Most of them are single cut, the double cut being used chiefly for the smaller saws. For purely triangular teeth the three-square files are employed, tapered for small saws, parallel or blunt for large ones. When a saw is gulleted it is generally necessary to use a round or gulleting file for the roots, and one of the flat or mill-saw files for the backs and fronts. In some cases, however, a flat file with one edge or with both convex is employed to file flat and gullet at once. A

half-round file—the pit-saw file—is also used for teeth with gullets.

Saws used for cutting timber must not be filed straight across, or they would work heavily and slowly. Only a keen corner is left standing up on the outside of each tooth (see the enlarged section, Fig. 105), and this is produced by setting the file at a double angle. One of these is an angle departing from the square-

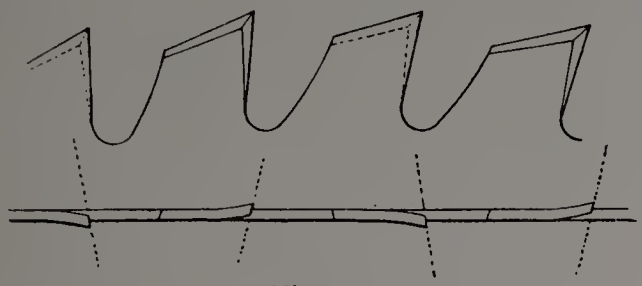


Fig. 107.

across position; the other from the horizontal, so that the file is held askew in two directions. The first is the principal angle, and it varies in saws for cutting hard and soft woods, the greater angle being given for the latter. One does not measure these angles—the eye is sole guide; but if tested, they will be found to average about 70° from the saw-blade, or 20° from the square-across position, and about 10° from the horizontal. The effect on the shape of the teeth

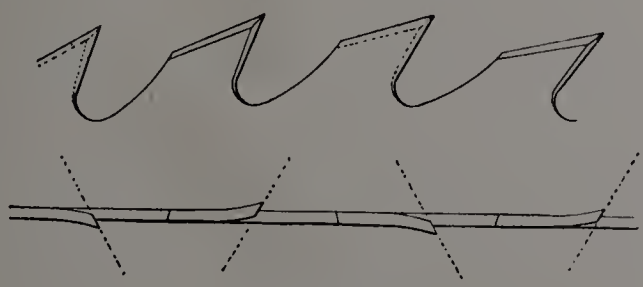


Fig. 108.

is seen in Figs. 105, 106, 107, and 108. Only the back of each tooth receives the pressure of the file in Fig. 106, though a trifle unavoidably comes off the front also. The fronts of teeth are only specially reduced if the pitch happens to have got irregular. All the teeth that lean away from the file are treated at once, and then the saw is reversed in the vice, and the alternate ones are done. That uniformity of angle is thus secured which conduces

to sweetness of cutting. In each tooth the shearing principle is embodied, the slope of the tooth edge producing a diagonal cut, instead of one straight across. The difference in sweetness of working is similar to that between a square mouth and a skew mouth rebate plane. In these views it is seen that the outer points of the teeth (*a*, *a*, Fig. 105), enter and sever the grain before the sloping edges follow to remove the dust. Fig. 106 shows the teeth of a hand-saw. Figs. 107 and 108 show the difference in the teeth of circular saws for hard, and soft wood respectively; Fig. 109 is a band saw blade.

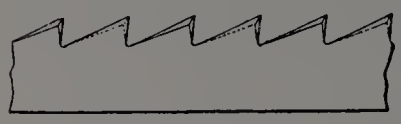


Fig. 109.

When a hand-saw is thus set and sharpened regularly it will not hitch, if handled with reasonable precision, excepting for an instant at the commencement of a cut, and that may be easily prevented by holding the saw lightly just at the start.

Of late years a number of machines have been introduced for the automatic sharpening of machine saws, both band and circular, using emery wheels in place of files. Absolute uniformity is thus secured.

Inseparable from sharpening is the work of gulleting (Fig. 93, p. 81, and Figs. 107, 108). To continue topping and sharpening without gulleting results in short teeth, and insufficient clearance for sawdust. So that after a saw has been resharpened from three to half-a-dozen times, the teeth are deepened in the gullets. This of course applies to teeth that are not triangular in shape, but have concave, or flat roots. A hand-saw for instance, or a triangular toothed cross-cut is deepened by the same filing which sharpens. But even in these it is not unusual to find teeth become shallower in time, due to the unconscious harder pressure exercised when filing towards the upper portions of the teeth, done to expedite sharpening. In hollow gulleting, the half-round edge of a gulleting file is used, or a blunt pointed parallel round file. This is the method where gulleting machines are not available. Many shops have these, and then an emery wheel with convex edge reduces the metal with much greater rapidity than any filing is capable of.

Forcing a saw, or forcing the work to a saw does positive damage, besides that of lost energy. It makes the saw hot, and that produces buckle in a circular saw, and overstrain in band saws, and inaccurate cutting in both.

The first makes itself apparent in a wabbling motion, and a loud disagreeable clanging sound when the stuff leaves the saw free, and it may, or may not leave permanent buckle after the saw has cooled. The best plan if this happens, is to let the saw run awhile until the heat has become equalised, and then dissipated. If the buckle remains, the plate must be hammered by a qualified man. Frequently the buckle can be got out by pressing the end of a piece of wood hard against the blade of the saw in the vicinity of the spindle, and thence outwards slowly towards the teeth, but stopping short of them. The object of this is to expand the saw around the spindle, and so equalise the temperature there with that of the teeth, and parts adjacent. A strained band saw ceases to run like a fine line, wabbling in a more or less wavy fashion.

Too rough setting will buckle a saw next the teeth. Buckle is often magnified by an attempt to take out a slight amount, by careless hammering. The way to remove it is to hammer, and spread the metal in the vicinity of the buckle, allowing the latter to spread itself out.

Any machine saw, whether circular, or band, requires to be packed close to the portion that is cutting. A circular, if of large size, is also packed in the rear. Without this precaution, it would be impossible to use the thin blades that are necessary to the economical conversion of timber. A thin blade with a moderate amount of set is the ideal tool.

With regard to the adaptability of saws to their work, the one with the coarsest teeth that is suitable for a job should be used as a matter of economy. To employ a fine saw, excepting for fine work, is wasteful of time. It is not economical to cross-cut thick stuff with a common hand-saw, while a rip saw is quite unfit for such work. It is wasteful to cross-cut thick stuff with a small tenon saw, or to use a dovetail saw for ordinary bench work. In proportion as the teeth become finer and more numerous, their capacity for removing dust is lessened. And although fine teeth are wanted for thin stuff, and exact sawing to line, they are not to be employed for the opposite conditions, simply because they happen to be so easily operated.

With respect to the methods of using hand and bench saws, the first point is to have the wood secure. The sawing stool or trestle is used to lay the board on for the ordinary work of ripping

and cross-cutting, two stools being used for long pieces, one for short ones, and the workman lays his right knee, or his left hand on the board to prevent it from rising. The saw is held at an angle of about 65° with the face of the board. Short pieces can often be cut closer to lines when held perpendicularly in the bench vice, as in sawing down the shoulders of tenons. The same position is adopted when using the compass, keyhole, or bow saws. The work is held steadily, the lines are seen better, and both hands are left free to operate the saws.

The tenon and dovetail saws are employed on the bench mostly, the work being laid thereon. But resistance to the saw is generally afforded by the bench hook, or the shooting board, or by the vice, or in some cases by the angle board.

A difficulty which unskilled amateurs and clumsy work-

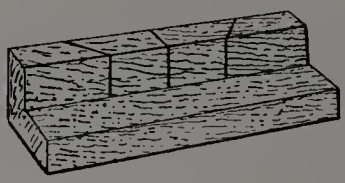


Fig. 110.

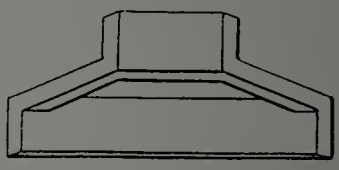


Fig. 111.

men encounter is that of sawing exactly to a line, and plumb. You see a cut started all wobbly, in the attempt to guide the saw straight, and to the line. This will also occur most readily in the case of a saw having too much set for its work, as, for instance, a hand-saw set coarsely to cross-cut but used for ripping. This difficulty can be avoided by sighting the saw correctly before beginning to cut. To saw plumb comes by practice. Apprentices may set a square on the board and up the blade of the saw; but they must soon discard that unless they want to be laughed at.

Figs. 110 and 111 show two forms of mitre blocks, in wood, and metal respectively, by which the movement of tenon saws is controlled at an angle of 45°. When any large amount of sawing has to be done either to length, or angle, by hand or machine, mechanical aids are utilised.

CHAPTER IX.

Files.

The Forms of the Teeth—Mode of Action—General Employment of Files—Sections—Derivations of—Longitudinal Forms—Degrees of Coarseness of Cut—Terms—Special Files—Length—Special Handling.

FILES and rasps must be classed with the scrapes, as a glance at the enlarged sectional form of the teeth (Fig. 112) will show. A keen file tooth will not retain its cutting capacity long, the tips becoming broken off almost immediately. A file is therefore a collection of scrapes, just as the ordinary saw is a series of chisels.

A file possesses a shearing action, because the rows of teeth are arranged diagonally, besides which the workman often gives a diagonal traverse to the tool in use. The teeth of files are cut by hand, and by machine. At one time the prejudice against the latter was very strong, but they are gradually ousting their rivals from the market.

Fig. 112.

Files and rasps number probably from two to three thousand different sizes. They are employed in nearly all trades, both for metal, and woodworking. The largest are used by the engineer, and the smallest by watchmakers, and locksmiths. Cabinetmakers and carvers employ them, and saw sharpeners, and farriers.

The principal points about any file or rasp are: The manner in which its teeth are cut, their degree of coarseness, the longitudinal shape, the section, and the length. The figures illustrate these cardinal points.

With regard to the sections, we see that files are in many cases the counterpart of the forms which they have to produce.

The flat files are obviously intended for flat surfaces. But they will of course produce convexities. If concavities have to be filed, the half-round, and similar tools are used, while in some cases longitudinal concavities are produced, as in the case of riffler files, besides which, engineers bend or crank their files for special purposes. In other cases files are used to impart exact angles.

Looking at Fig. 113, we see that sections derived from the rectangle are the square files A, the flat files B, which occur in various thicknesses, and longitudinal outlines. A special flat file

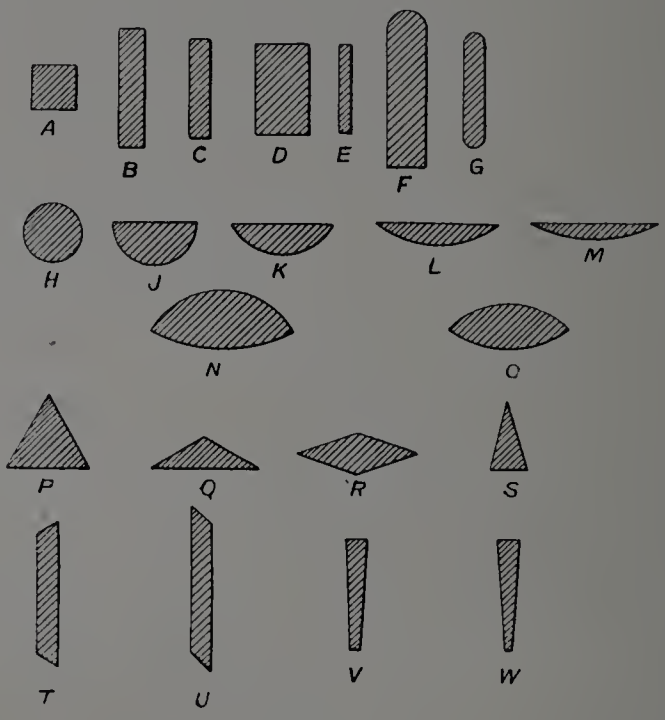


Fig. 113.

is the mill file C, which is thinner for a given width than the flat file B. A very thick flat file D is a pillar file, while a very thin one E is a warding file. Often flat files have both, or one edge rounding, as at F, G. Rasps are made in similar sections to the files. Sections derived from the circle include the round files H, the frame saw, or pit-saw file J, the half-round K, the cabinet files L, M, the double half-rounds N, O, whieh contain different curvatures on opposite faces. Sections derived from the triangle are the three-cornered, or three-square file P, the cant file Q, the slitting, or feather-edge file R, and the knife file S. Compounded

of the square and triangle are the swaged reaper files T and U, and the reaper knife files V, W.

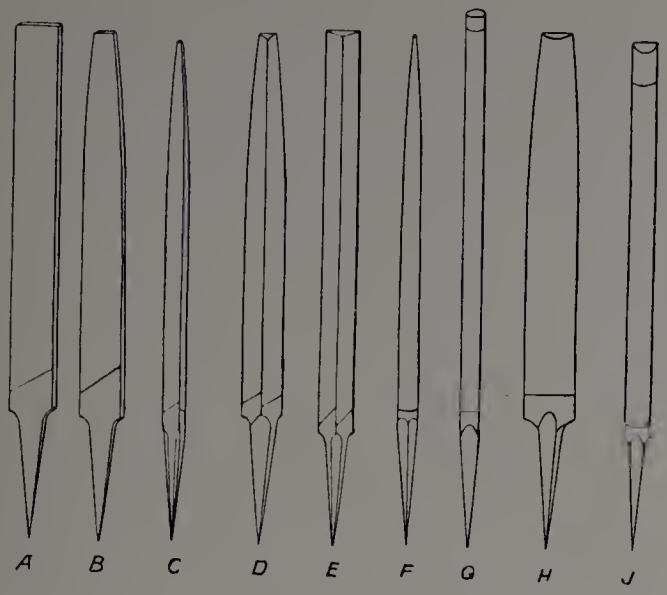


Fig. 114.

Coming to the longitudinal forms of files, we have in Fig. 114 first, A, B, C. A is a hand file, which may be nearly, or quite parallel. When a file is parallel throughout its length it is termed blunt pointed, to distinguish it from the ordinary equalling file, which always has a slight curvature lengthwise. B is a tapered file. It may be nearly straight-tapered, or of a bellied form, as in the figure. But any such file is always considerably smaller at the point than it is next the tang, differing therefore from A. The square file C is tapered in the figure and bellied. It is also made parallel, or blunt. D and E represent respectively the three-square file, and the three-square blunt saw file, one being tapered and bellied, the other parallel. F and G are round files, the first being commonly termed a rat-tail, the second a gulleting, being used by sawyers, for filing the roots or gullets of large saws. H is a common half-round, and bellied file; J is a parallel half-round, also termed a pit-saw, or frame-saw file. Most of these can be had single, or double cut, and also as rasps, the difference of which is shown in Fig. 115,

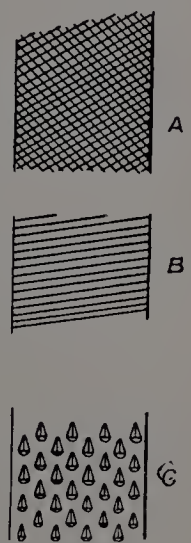


Fig. 115.

A being the double, B the single cut, and C the rasp cut. In A the teeth are formed by the intersection of crossing chisel cuts, so producing isolated points. In B the lines run singly in one direction, forming continuous cutting edges. A and B are cut with chisels, the rasp teeth C are thrown up by a punch. Most files used by metal workers are of double cut type. The single, or float cut are largely used by sawyers for tooth sharpening. Rasps are used by cabinetmakers, carvers, farriers, and core makers.

The degrees of coarseness of cut are designated by the following terms :—Rough, Middle Cut, Bastard Cut, Second Cut, Smooth, Double Dead Smooth. The foregoing relates to double cut files. In single cut the corresponding terms are Rough, Middle, New Cut, Smooth Float, Second Cut, and Smooth. In rasps, the terms are Horse, Rough, Middle, Bastard, Second Cut, Smooth. These terms are relative. The coarseness designated by any one of these terms increases in proportion to the length of a file. So that a coarse file in one size would have a number of teeth per lineal inch corresponding with a second cut in another length. A 12 in. file is generally taken as a standard in estimating the number of teeth per inch. Rifflers are double-ended curved files, or rasps, used by cabinetmakers and carvers. Sometimes they are single-ended, and used with wooden handles like the majority of files.

There is a certain class of file, the safe edge, in which one edge is left uncut. It occurs in the taper, and parallel hand files, and in some of those used for saw sharpening. Its object is, of course, to prevent material from being removed from some portions of a piece of work while others are being filed. Some files have special names which designate their exact uses, such as cottar, warding, slitting, escapement, pivot, and balance files.

Generally speaking, files range in length from 2 to 24 in. but this depends largely upon type; 16 or 17 in. is the usual limit, and many types do not go beyond 8 or 10 in.; while in others the limit is from 2 to 3 in.

For filing large flat surfaces, the handle of the file must necessarily be elevated, in order to enable the worker's hand to clear the surface. This may be done by either bending the tang upwards to an angle sufficient to raise the handle off the job, or by cranking the tang—that is, bending it upwards, and then along horizontally again. This gives a more direct thrust to the file than

simply bending at an angle. Bending may be dispensed with by employing the device in Fig. 116. A special handle is made by bending round rod as shown, one end being tapped into an ordinary hexagon nut. The latter is filed out to fit the tang of the file, and driven tightly on the latter, the plain end of the rod resting on the file a little way up. Several variations on this common device are employed, but their principle is similar.

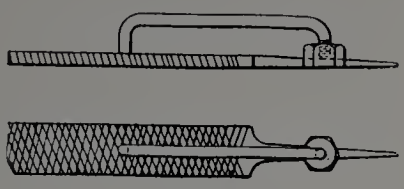


Fig. 116.

When the teeth of files become choked or "pinny," they are brushed clean with card wire. Specially obstinate bits of metal must be picked out with a pointed bit of wire.

CHAPTER X.

Milling Cutters.

More Economical than Single-Edged Tools—Multiplication of Edges—Discounted by Shallowness of Cutting—Rake—Durability—Spiral Twist—Period of Rest during Revolution—Question of Speeds—How effected—Average Rates—The work of each Tooth—Necessity of keeping edges sharp—Heavy feeds—Pitching of Teeth—Direction of Feeding—Varieties in forms of Cutters—Face and Edge Mills—Their proper Spheres—Gang Milling—Devices adopted in Building up—Milling Parallel Grooves—The Wear of the Mills—Combinations of Edges—Angular Mills—The case of Profiled Forms—Examples—Profile Milling compared with Grinding—and Planing—Profiling Machines—Face Mills with Inserted Teeth—Methods of Insertion—and Securing—Advantages—Staggered Teeth in Solid Mills—Taper Shank Mills—Formed Mills—Lubrication of Cutters—Pickling.

THE reason why milling cutters effect more economy in time than single-edged tools like those used on planer, shaper, and slotter, is that they embody a multiplication of tool edges. An ordinary roughing tool cuts by means of its single point, a finishing tool by its narrow edge. Each removes a shaving equal to the width of the point, or edge which is operating, and no wider. To remove material from a surface of several inches in width, a traverse movement must be given to such a tool. Milling cutters are simply a collection of numerous cutting edges which operate in rapid succession on the same surface, and they will act over a width of several inches at once, without the loss of time involved in traverse feed.

On the other hand, it is to be remembered that very deep roughing cuts cannot be taken with broad milling cutters, because, as usually formed, they are scraping tools—that is, tools the cutting faces of which stand perpendicularly to the face of the work, whereas machine roughing tools have a large amount of top rake, by reason of which they are capable of much penetration. But this disadvantage is only a slight set-off against the advantages to

be derived from the use of many cutting edges of great width. Mills must be so formed that they will give good mean, or average results on all metals and alloys, and therefore suitable for iron and steel, for brass and gun metal, the same cutters being generally used on all alike. As they generally have faces perpendicular to the face of the work which is being operated upon, this formation limits the depth of the cut, and thickness of chip removed.

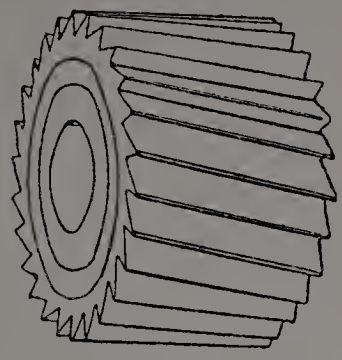


Fig. 117.

Fig. 118.

But depth of cut in this case is of less importance than durability of the cutting edges. When the edges become dulled, regrinding is a more tedious process than that of single-edged tools, and it is therefore more economical to preserve the cutting edges as long as possible, even at the sacrifice of some penetrative power. And this loss is much more than compensated for by the multiplication of those edges. So that here, as in most other matters, practical conditions rather than theoretical considerations, settle the ultimate forms of the cutters.

In all but the narrowest mills, the cutting resistance is diminished, and a smoother surface produced by imparting a spiral twist to the teeth, producing a shearing cut. In some of large diameter and width, the principle is still further developed by breaking up the spiral into numerous

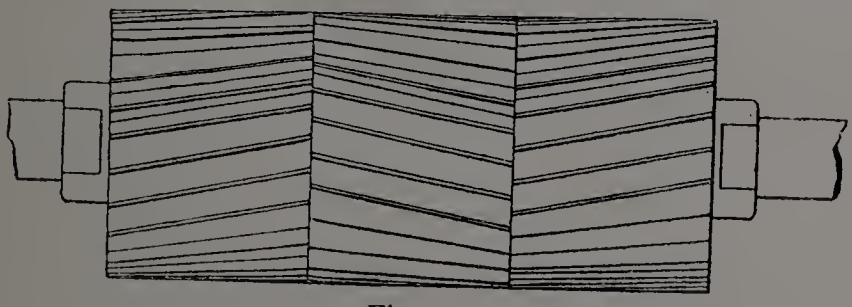


Fig. 119.

short teeth (Fig. 154, p. 117), and also by arranging them in both right and left hand spirals (Fig. 119), similarly to the teeth

of double helical wheels. The resistance is thereby much reduced, and deeper chips can be taken, while experience has proved that the short cutters do not become broken, as it was anticipated they might be.

There is an important distinction between the edges of the milling cutters, and the single tool-point of the planing and allied machines. It is that the single tool-point cuts almost continuously, its only period of rest being that which occurs during the return or non-cutting stroke. But any single edge of the milling cutter is inoperative during by far the greater portion of the revolution of the mill. It has, therefore, a much longer time in which to cool than the single tool-point, and it can consequently be run faster; and this goes a long way towards compensating for diminished cutting power due to the absence of front rake. In this respect it compares most favourably with the single cutting tool used in planer or shaper, which is cutting during about two-thirds of the time, and has little time in which to cool off; and the lathe tool, cutting all the while.

In order to obtain the best results from milling, attention must be given to the rates of speed, by varying the rate of revolution of the cone spindle to suit the diameters of cutters. The rate of surface travel in feet per minute is the important matter, just as it is in the lathe, and other machines. Hence the belt must be shifted with any material alterations in the diameter of cutters used. This is an obvious matter, but one which is frequently neglected.

So many causes affect speeds, that almost every job must stand by itself. There is the question of the condition of the cutters themselves—whether properly formed, whether sharp, or dull, ground regularly, or otherwise; suitably tempered for the class of work on which they have to operate, or not. Then there is the relation of speed to depth of cut, and surface feed, the class of cutter being used, the nature of the metal or alloy being operated on, the kind of work being done. So that the problem resolves itself generally into one of experience in given classes of jobs.

Milling cutters can be run generally at from two and a half to about three times the cutting speed used with single-edged tools. With shallow cuts, and moderate feeds, cast iron may be milled with cutters having a surface speed of 40 to 50 feet a minute, cast steel from 20 to 30, wrought iron from 50 to 70, and brass

from 80 to 120. For light finishing cuts these rates may be increased by from 50 to 100 per cent. Milling cutters are being made of the new high speed steels, with higher rates, and feeds.

Cast iron is milled dry; other metals and alloys, with water, or preferably oil.

To obtain the perfection of operation from mills, it is obvious that each tooth should do its fair share of work. If a sixteenth of an inch is being removed at one revolution of a mill, and it has 60 teeth, it means that each tooth should be removing $\frac{1}{60}$th of $\frac{1}{16}$ in. That is a very minute thickness, and since the radial dimensions of the teeth may well differ from one another by that amount, or more, without being perceptible, it follows that the duty of cutting may devolve on, say, 10, or 20 teeth of the 60. If the rate of feed or travel has been speeded to suit the work which a perfect mill would do, that is a mill in which each tooth of the 60 would be cutting; then obviously 10 teeth will not do the work, and they will become heated, and the speed will have to be reduced. Or, again, if the teeth are ground practically perfect, but are worked after they have become dulled by use, to save the trouble of re-grinding, then the mill will become overheated, and the speed will have to be reduced.

Milling cutters obviously should never be worked until their cutting edges are dulled so much as to be very visibly so. The passing of the finger lightly over the edge, which should be very keen, is a better test than the sight. One or two movements of the cutters under a fine grade revolving emery-wheel will restore the edges.

The degree of stability of the machine, and the condition of the mill will make a difference of 50 or even 100 per cent. in cutting feed. If a high feed is attempted with a mill in bad order, the belt will slip, or the teeth break, or the tool chatter. The heavier the feed measured in depth of cut, the more work there is thrown upon the cutters, and the greater the tendency of the work to bend, or spring away from the cutters, or *vice versa*. In light, unsupported work, this has to be reckoned with quite as much as the heating of the cutters, because their profiles will not be accurately reproduced on surfaces which do not remain in rigid contact with them. Hence the rate of feed, and depth of cut are affected both by the stability of the arbor and its supports, and by that of the work, which is also influenced by its height or distance from the table,

by overhang, by its own rigidity, and similar kindred matters. It is therefore of little use to give rates of feed and travel unless with certain machines doing certain work. The limitation to the speed and feed of mills is also, other things being equal, partly that due to the pitching of the teeth. The limit of speed appears to be that at which the teeth become choked with the chips. This is the condition termed "crowding," in which the mills are driven so fast that the chips have not time to get away from the teeth. Until this is reached, the higher the speed and feed the more economical should the results be under any given set of conditions.

Mr Addy gave a rule for obtaining the pitch of the teeth of mills of all diameters from 4 to 15 in. :

$$\text{Pitch in inches} = \sqrt{(\text{diameter in inches} \times 8)} \times 0.0625.$$

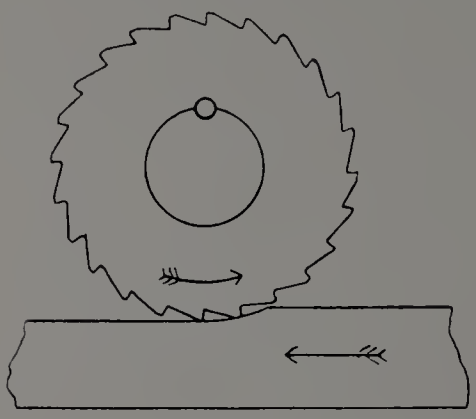


Fig. 120.

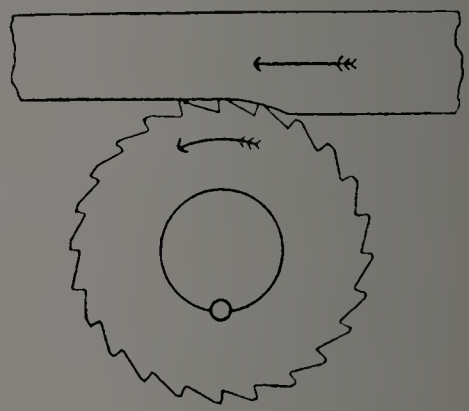


Fig. 121.

Or put more tersely by Mr Gray thus : "The number of teeth in a milling cutter should be one hundred times the pitch in inches. So that if there were 30 teeth in a cutter, the pitch would be 0.3 of an inch. Actually the teeth of average mills range between about $\frac{1}{4}$ in. and $\frac{3}{8}$ in. pitch.

Some controversy has arisen respecting the better method of feeding the work, whether towards, or with the revolving cutter, and some differences of opinion between people well qualified by practice to form a judgment on the matter exists. But all reason seems in favour of the long-established method of feeding towards the cutter. Thus, let Fig. 120 represent the old style of feeding, and Fig. 121 the other. In Fig. 121 the depth of cut is least at the commencement and greatest at its termination. In Fig. 120

the depth is greatest at the commencement. The arbor would be less liable to chatter in the first case than in the second. In Fig. 120 the constant pressure of the work tends to prevent vibration in the arbor. In Fig. 121 the tendency is to vibrations of varying intensity, throwing the mill off the work, and causing chatter. Again, in Fig. 120, after the mill has struck the work, it cuts soft metal continuously. In Fig. 121 it is continually cutting from the skin downwards, which soon dulls the cutting edges. These considerations are all in favour of the common practice, notwithstanding that the experience of some men has declared itself in favour of the other method.

The number and variety of milling cutters is very large. They comprise solid cutters, and cutters with inserted teeth; plain cutters for operating on plane surfaces by their sides, and by their ends on one surface only at a time, combinations of plain cutters for operating on several surfaces simultaneously; cutters of irre-

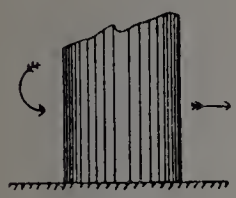


Fig. 122.

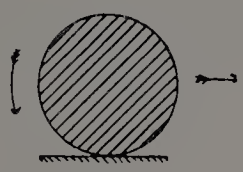


Fig. 123.

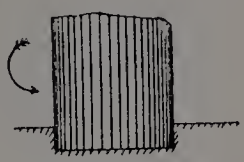


Fig. 124.

gular outlines—curved, angular, symmetrical in form, or otherwise, for various classes of work, made either solid, or composed of several mills on a single arbor. The solid mills range from $\frac{3}{8}$ in. or $\frac{1}{2}$ in. in diameter up to 6 in. or 8 in., and mills with inserted teeth up to several feet for exceptional duty. The width of mills will range from $\frac{1}{16}$ in., used for slitting, up to a couple of feet or more, being limited only by the width of machines.

The primary distinction between cutters is that of end or face mills, and edge mills. In the first case, the end of the mill cuts; in the second, the edge. The first cuts, therefore, in a plane at right angles with the axis of rotation, the second in a plane parallel with that axis. Each is better adapted for some kinds of work than others, but each is also used indifferently for a large variety of operations. Thus, for example, it does not matter as regards ultimate results whether a cutter produces a plane surface with the end mill (Fig. 122) or with the edge mill (Fig. 123). Neither would the results be different if the edges of a groove were cut by

the sides of an end mill in Fig. 124, or the sides of an edge mill as in Fig. 125, of the kind shown in perspective in Figs. 126 and 127 —and these examples are typical of many which occur in every-day practice. Neither is it of any consequence whether plain

Fig. 125.

faces or edges occur in horizontal, or in vertical planes. An edge mill (Fig. 128) set on a vertical spindle, will cut faces in a vertical plane; and a face mill (Figs. 129 and 130) set on a horizontal spindle, will cut faces in a vertical plane. At present we are only considering ultimate results in reference to truth and finish, and

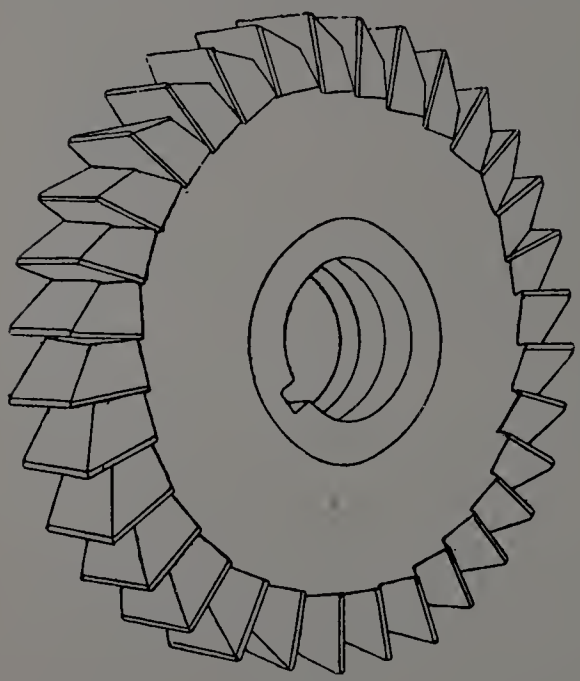


Fig. 126.

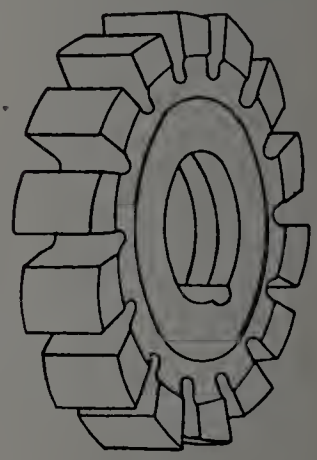


Fig. 127.

not the element of time, which will sometimes determine the choice of one method in preference to another.

But when we get away from work of small and moderate dimensions, and plain work, conditions often render one method preferable to another. Thus, when large surfaces are in question,

the edge milling is generally preferable to face milling. Large surfaces are often long as well as wide; and if not, then it is often desirable to make up a considerable length by arranging a number

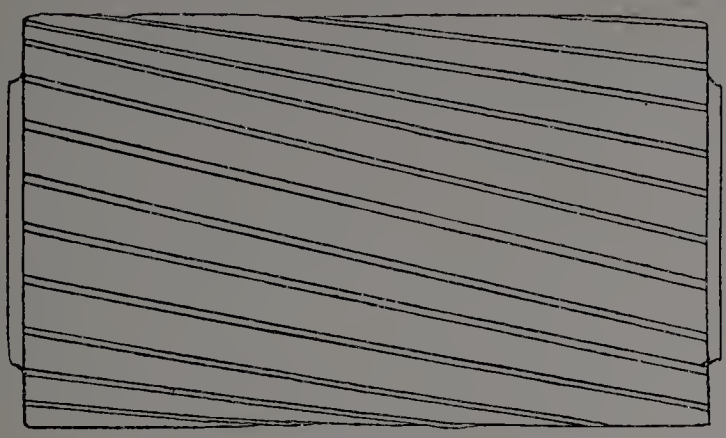


Fig. 128.

of pieces in series, and tooling over the lot. Long edge mills employed on planer types of machines are, then, the best to use, because the whole area can frequently be gone over with a single

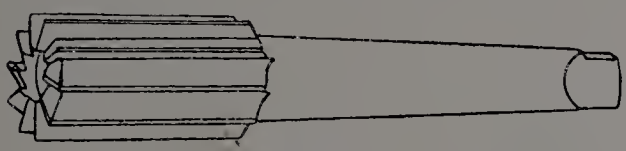


Fig. 129.

traverse. The mills may be single, or the length may be made up of two or three narrower mills of the same diameter, preferably with diagonal teeth in opposite directions as in Fig. 119, p. 99.

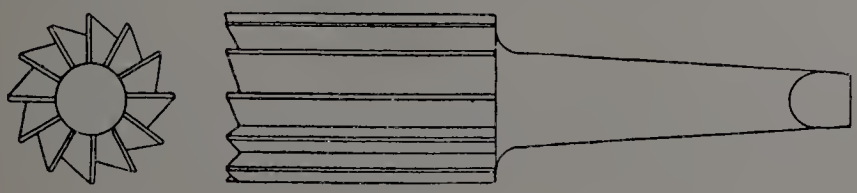


Fig. 130.

For all gang milling, the horizontal position of the spindle is best. The work is held more firmly on the table, and is steadier than it would be if held otherwise. A long arbor can be used more readily on a horizontal spindle than on a vertical one.

An exception to the rule that large surfaces are more suitably tooled with horizontal spindle machines and edge mills, occurs in the case of large face mills with inserted teeth. These, however, are not employed so much in the finer work of the machine shop. Their more special function is the rough-facing off of the ends of castings and forgings, and the axis is, as a rule, horizontal; though smaller face mills with inserted teeth are sometimes used on vertical spindles.

The great length of the arbors of the planer millers renders the building-up of cutters in gangs a necessity. There are three or four devices adopted in building-up gang mills, when it is necessary to maintain a uniform breadth over extreme edges, compensating for the diminution of width which naturally follows on wear or regrinding. The same devices are serviceable as a means simply of preventing a mark on the work due to the jointing of the mills. One of the earliest adopted was that of having a diagonal joint. Another consists in making the teeth (Fig. 131) to overlap. But this is only practicable when there are teeth on the ends. The simplest plan is to make a shallow clutch or claw joint between the ends, either slotting the mills right across, or partially only (Figs. 132 and 133). Both methods are adopted, the former being the simpler. Either effectually prevents the formation of a joint mark, and compensation for wear is effected by the insertion, when necessary, of a sheet of paper or metal between the joints. Fig. 134 illustrates a pair of mills arranged with a plain distance piece between. They can be used for milling a pair of grooves, or outer faces, or inner faces only. These are employed for nut milling also. Fig. 135 illustrates a gang mill made for a special purpose by the Becker-Brainard Company, to cut on eight faces, the section of its work being seen beneath. The outer faces are tooled by inserted tooth mills. Provision is made for side adjustment of the mills A, A by the screwed collar B, a method used with success.

Although the gang-mills have a formidable appearance, as though of necessity most costly tools, yet they are not so in fact in shops where milling is done extensively. Given a good stock of cutters to select from, and suitable arbors and collars of different lengths, almost any required combinations of cutters can be built up for face and edge work, for operating on several surfaces at once, and on several distinct pieces at one time.

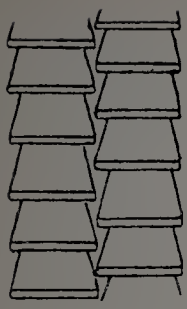


Fig. 131.

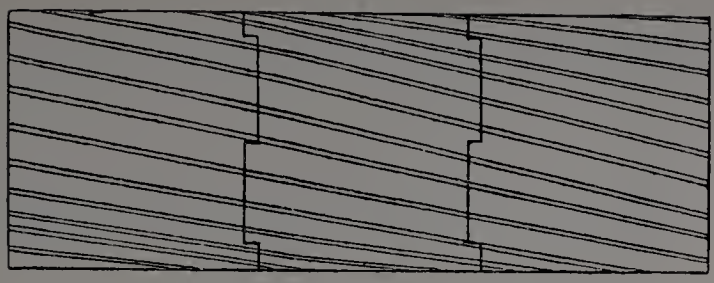


Fig. 132.

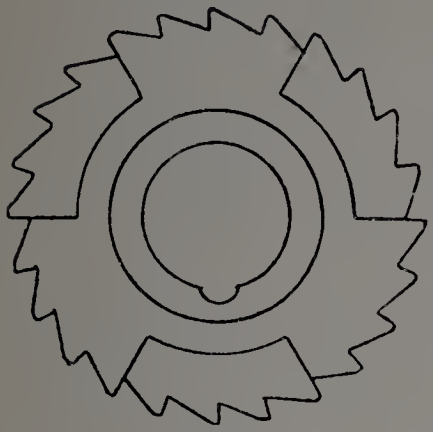


Fig. 133.

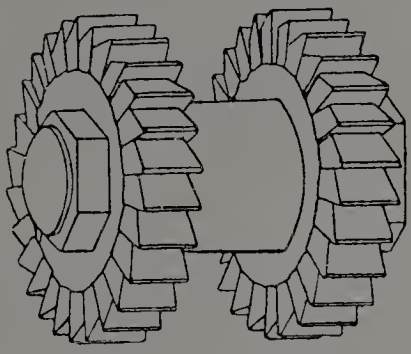


Fig. 134.

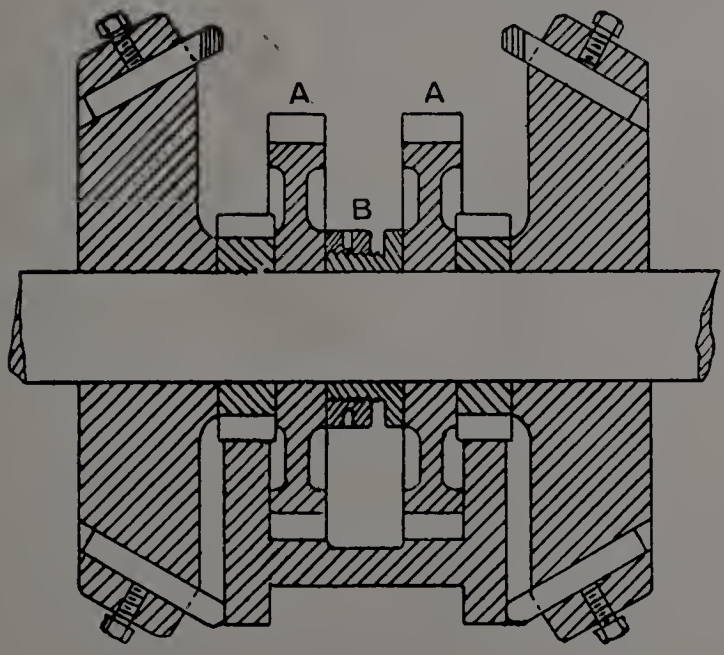


Fig. 135.

It is easy to arrange gangs of cutters to operate either on different pieces of work, or on different parts of the same piece. Thus, several parallel grooves can be tooled with cutters arranged as in Fig. 136, with distance collars between them, the grooves being tooled on edges and on bottom faces at once. This is one example in which there is no question at all respecting the over-

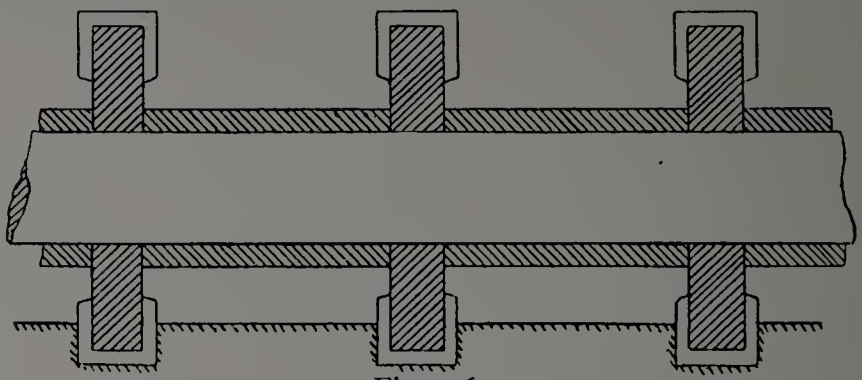


Fig. 136.

whelmingly greater economy of milling over planing. The larger the number of grooves the larger the economy.

Most of the narrow-edge mills like Figs. 126 and 127 are face mills also, having teeth cut on both faces. By this device faces and edges can be cut on work simultaneously as in Fig. 136. Arranging as in Fig. 137, a central mill can be cutting, in

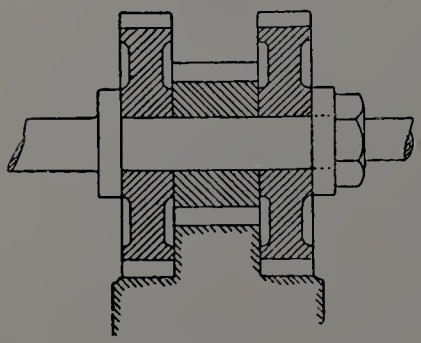


Fig. 137.

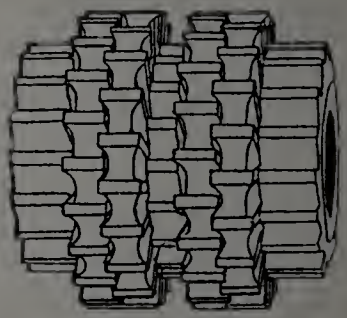


Fig. 138.

addition to the others. Fig. 138 is another combination. These examples are indicative only of the very many combinations which it is possible to build up with mills of different dimensions and shapes to suit different classes of jobs. Angular grooves, convex and concave sections, and any irregular forms can be tooled alone, or in combination with plane surfaces, with milling cutters.

Angular mills of various sections—of which Figs. 139, 140, are typical—are used for a variety of purposes, as for grooving milling cutters, cutting vees, &c.

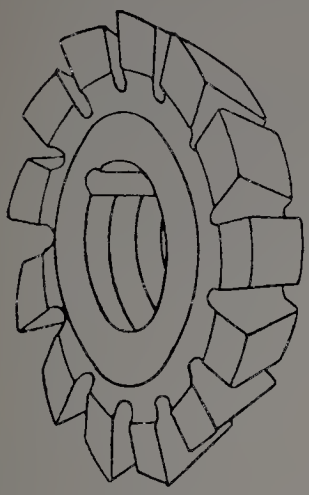


Fig. 139.

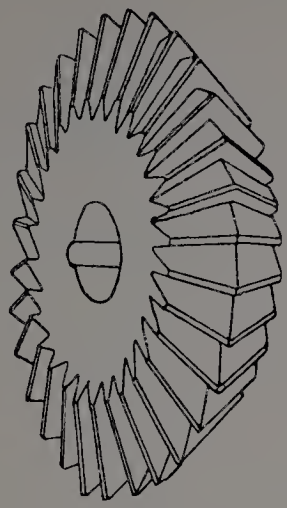


Fig. 140.

The great breadth of surface which can be tooled by a milling cutter, and the fact that the time required for the return stroke of the planer and shaper is saved in milling, do not represent the

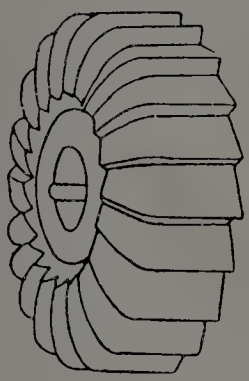


Fig. 141.

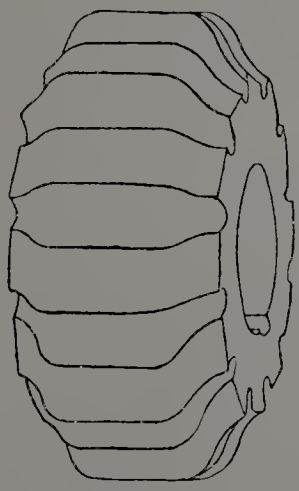


Fig. 142.

whole of the important economies obtained. The greatest advantage often lies in the fact that any number of profiled forms can be milled all alike, by having these forms embodied in the shapes of the milling cutters. In large volumes of work this is where the milling machines score most heavily. It is the case in

some parts of cycle fittings, as pedal cranks and sprocket wheels, the mills for which are shown in Figs. 141, 142. Lathe beds of vee'd section and machine slides are similarly treated (Fig. 143).

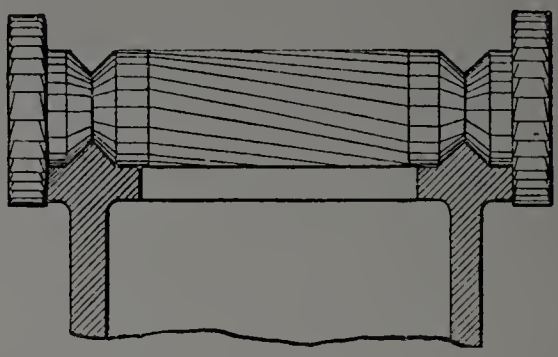


Fig. 143.

A familiar example of the value of profiled cutters is seen in the cutting of gear wheels, which otherwise would have to be planed out. The teeth of racks are cut similarly. Several teeth can be cut simultaneously by arranging several similar cutters in parallel series. The teeth of worm-wheels are cut with hobs, which are really mills with coarse teeth.

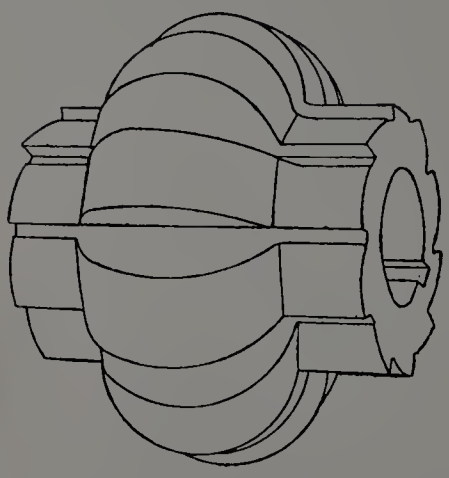


Fig. 144.

The practice of some firms is to mill out the semicircular seats of plummer blocks and divided bearings with a tool like Fig. 144 in preference to boring them. At the same time, if the cutter is so profiled, the top faces and the shoulders for the cap are milled. This is economical in one respect. But the cutters are expensive, and when they wear their dimensions become altered. The use of milling cutters in preference to other methods of tooling for any given job must always be decided on its merits.

Profile milling is invading the work of the lathe. Though for producing circular work of large diameter the lathe retains its pre-eminence, yet the milling machine is appropriating some sections

of that. Many gear-wheel blanks are now milled circularly instead of being turned, including the blanks for spurs, bevels, and worms. Profile-cutters are so eminently adapted to this class of work, ensuring that a number of blanks will be alike, that their employment will increase.

There is practically little or no choice of methods in profile work, for the milling machine takes it nearly all. It cannot be done with close precision by grinding, because the traversing motion which is so essential a feature in grinding is absent, and without this true grinding is not possible. If an emery wheel is turned to a profiled form it will not retain its section long enough for very accurate work. It is adapted for grinding concave and convex edges for certain purposes, but not for mutual and exact fitting of parts. Thus, it is very suitable for gumming or deepening the teeth of circular saws, for finishing the concavities of bearings which are less than hemispherical, as in axle-boxes and in the comparatively rough bearings of trolleys, and for imparting the convex edges to flat-webbed connecting rods, &c. These are typical of a considerable volume of work within which the profile grinding-wheel finds its proper sphere. But it does not include that larger range which is almost wholly appropriated by the profile milling cutters.

The latter retain their shape unaltered until worn out by repeated regrindings, and are accurate enough for the most exacting requirements of the engineer.

There is no comparison between the work of a profiled tool and that of separate cutters in planers, which would have to be readjusted several times in the classes of work named above, and which are typical of many other jobs. Planing tee-slots involves the use of both right and left handed tools, and tools for the bottom and top edges, requiring careful feeding by hand. Done by milling, a cutter first roughs out the width of the narrower slot, and the tee-shaped cutter finishes at one traverse without hand feeding at all. The work of three distinct cuts on the planer, with right and left hand tools, is done at one traverse of the milling machine.

Edges are profiled on both vertical and horizontal machines. The profiling pin in these machines is tapered, in order to afford, by means of its vertical adjustment against the edges of the former, of the use of roughing and finishing cuts, and of adjustment for the wearing down of cutters. The pins are held in a boss in the

smaller machines, so that the distance of their centres from the centre of the spindle is fixed. In the larger machines the pins move in slots, so that the centres can be varied (Fig. 145). The vertical adjustments of the pins are readily made, and their positions fixed by lock nuts.

The former, or templet A, is made of stout steel metal, preferably of steel for durability, and is bolted to a block on the bed, so leaving the profile edges clear for the pin to trace round. The templet is pulled against the pin B either by the lever in the small

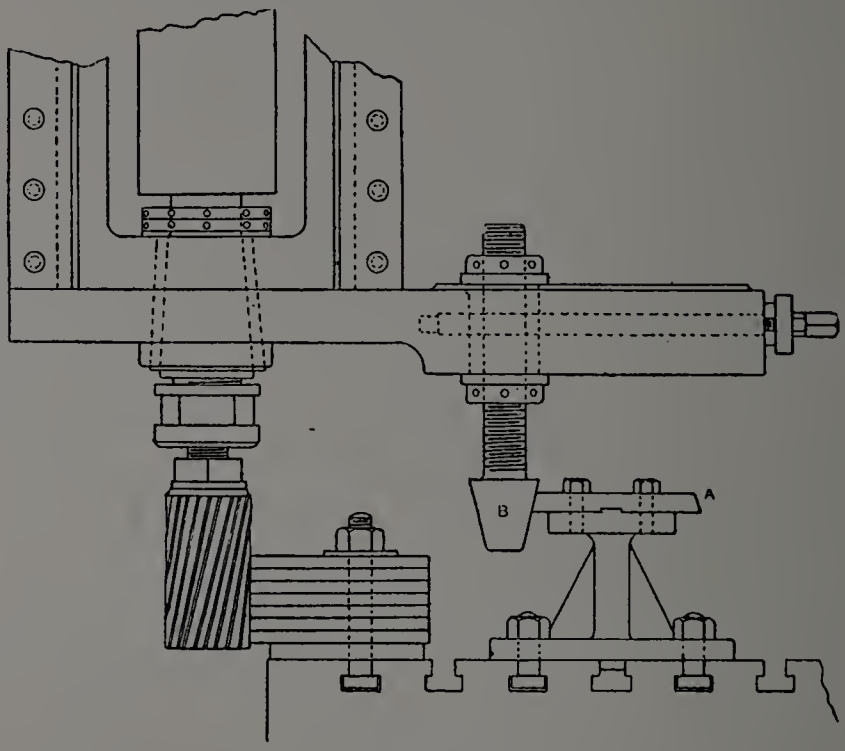


Fig. 145.

machines or by the weight in the large ones. The vertical adjustment of the slide is controlled by a stop, and stops control the horizontal position of the slide.

Face milling is a practice which is adapted to an extremely wide range of work. It is more convenient in many cases, and more economical than edge milling. The cutters need not be expensive, and there is scarcely a limit to the size in which they can be made.

The largest face mills have inserted teeth; and the general method of insertion is to drill or cast holes in a block or head of

cast iron, insert the separate tool points or teeth, and pinch them in place with set screws. In some cutters the tool points are inserted diagonally at an angle of a few degrees, to impart some desirable amount of front rake. The cutters are turned up in place, then removed and backed off, hardened, and replaced. That may be called the standard and the older practice. Of late years there have been several variations therefrom, the endeavour being to avoid the work of tapping a number of holes, and also to

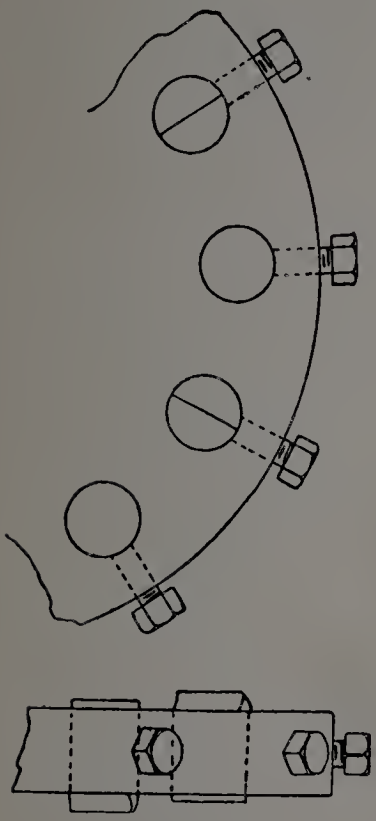


Fig. 146.

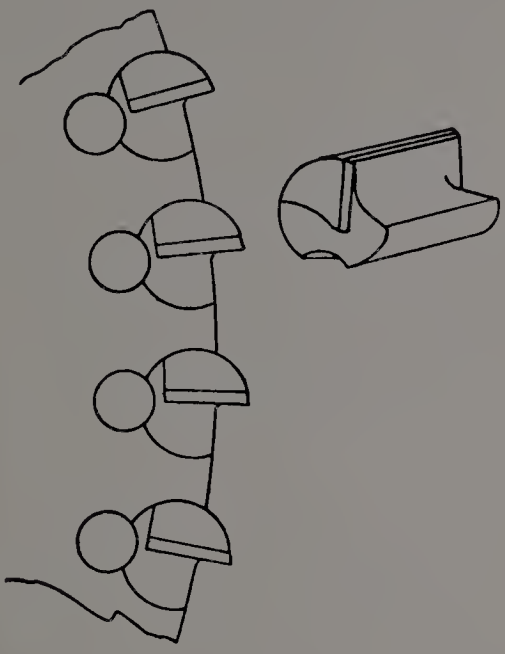


Fig. 147.

make a firmer job. Mills have been made in which the teeth have been cast into the block, and they are said to have answered well. In the absence of experience of such cutters, one would expect to find the temper drawn, and to find them working loose.

When teeth are inserted and secured, they may either be inserted in holes in the body, or in slots in the edges of the body. It is not necessary to set them at an angle in order to impart front rake, though this is often done. It is simpler to fit them squarely, and impart the front rake by grinding the face of each tooth.

The following examples are taken from the practice of the Becker-Brainard Company. Fig. 146 is a face mill, duplicated. It can be used for facing only, or for slotting a groove, or for finishing the faces of two separate pieces of work, brought up against each face. The tool points are of circular section, and are held in position each with a set screw.

Fig. 147 is an example of a cutter in which the tool points are still circular, but inserted in the edges of the body. They are secured by taper pins, fitting partly into the cutter, and partly into the body. Or screws may be used instead of taper pins. The ends of the tool points can be used alone and singly, or

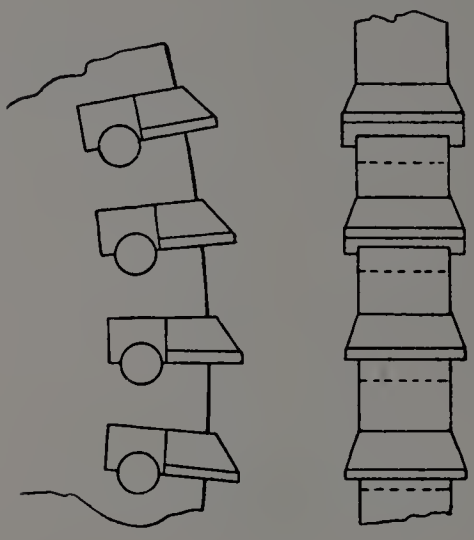


Fig. 148.

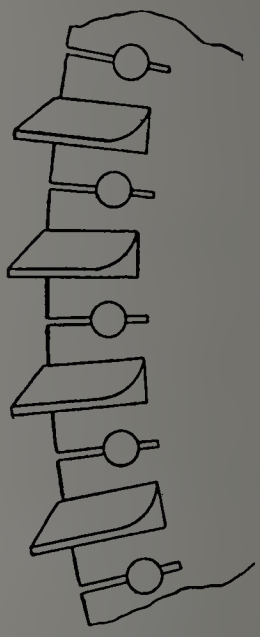


Fig. 149.

the edges and ends, the combination being that of the two types of mills.

Fig. 148 is a variation of Fig. 147, though it fulfils the same functions. The cutters are angular instead of circular. They fit grooves around the body, and are held in position each with a taper pin.

One of the most common devices for securing teeth is by the insertion of pins midway between the cutters, as in Fig. 149. The cutters fit in their grooves, and the metal in the body is slotted midway between each to permit of some elastic movement. The insertion of a tapered pin in a hole drilled and reamered in

the centre of each slot opens the metal, and produces pressure against the cutter flanks to right and left.

The adoption of the practice of inserting tooth points into a body of cast iron is but an extension of the principle of tool points in tool-holders *versus* solid tools. The cost of the steel alone for large solid milling cutters is very heavy. Then there is the expense of producing the teeth on a universal milling machine, or on a

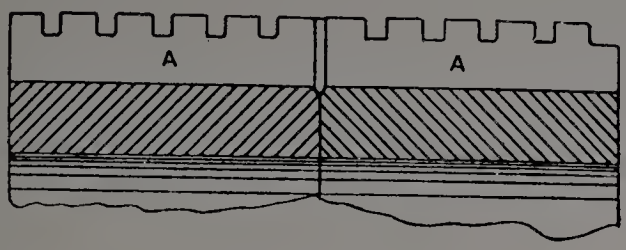


Fig. 150.

special cutter-forming machine, which is a slow process. And after the work is done, the mill may fail in the hardening through want of homogeneity in the steel, or owing to failure in carrying through the operation. Then there is a further risk of the teeth becoming injured in working, being fractured or jagged from causes inherent to the machine, or in the hardening, or in the

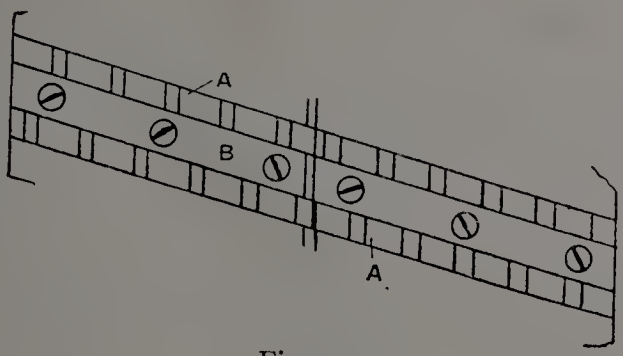


Fig. 151.

nature of the material which is being operated on. So that large cutters are costly and troublesome. Having cutters with inserted teeth, the very best quality of steel can be used for the teeth. They need not be expensive to make, or troublesome to temper. If a tooth becomes broken it is easily replaced. In these respects, therefore, the inserted tooth mill is the analogue of the tool point gripped in a tool-holder.

The same device, that of tool points, which is carried out in the face mills, has been adopted in some large axial mills. In one type of these the teeth are formed in continuous strips of steel, instead of as points driven into drilled holes. Fig. 150 shows a part section of a mill built in two lengths. The strips A, A lie in grooves planed diagonally across the body (Fig. 151), and they bear wholly against the grooves on one side (Fig. 152), but the greater portion of the metal is removed from the side opposite to

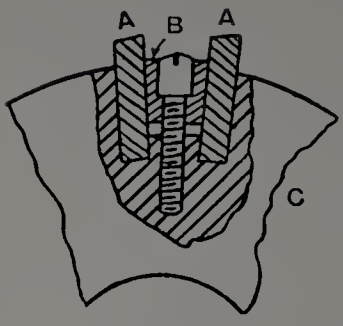


Fig. 152.

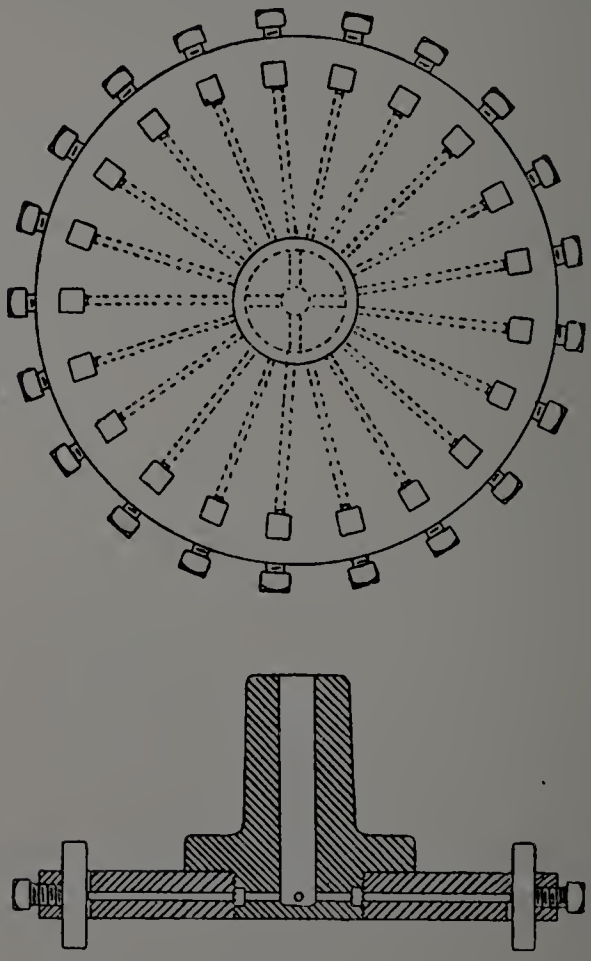


Fig. 153.

receive a wedge piece B. The latter is held down with screws tapped into the cast body C, and presses against adjacent strips.

The latter are turned up in place, and their faces milled radially, as in solid mills. They are then serrated to form single cutting teeth. The serrations are not imparted in a helical curve, but in parallels, the teeth alternating (Fig. 151). Each alternate set is turned with the others removed. There is, therefore, continuous cutting across, with the advantage of the action of single-tooth points.

The large slabbing cutter shown in Fig. 153 has provision for lubricant being forced directly on the cutters, which is effected by distributing the oil from the inside, through the hollow spindle, and thence to the radiating holes which meet, and discharge at each cutter, through a small hole underneath. This is a good device for ensuring coolness of working and thorough washing away of chips, but the expense of making would be a deterrent to its general use, while practically as good results can be secured by an ordinary outside flow of pumped lubricant.

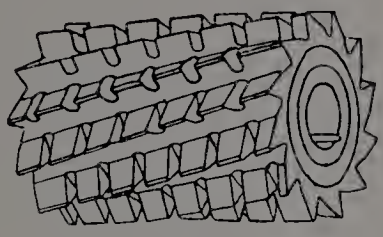


Fig. 154.

For rough-cutting wide surfaces, the toothed mills (Fig. 154), act more expeditiously, and with less expenditure of power, than the mills with continuous cutting edges. The reason is that they operate in detail on a number of small areas in rapid succession, so breaking up the metal into chips, instead of removing it in one long shaving. The principle of their construction is simple. It is as though the teeth of an ordinary spiral mill were broken up into a number of separate teeth by cutting a square-threaded treble screw thread round the mill. The idea at first was deemed contrary to sound practice, because it was thought that the corners of the numerous short teeth, being unsupported, would become broken off when cutting. Experience, however, has demonstrated the fallacy of this idea, and these toothed mills are used extensively in England and have been adopted in America, when heavy cutting has to be done.

In the case of cutters the sides of which are curved or tapered towards the circumference, the shape can be retained under constant regrinding by a device first embodied in Messrs Brown & Sharpe's formed cutters for gear wheel teeth and some gang mills. It consists in striking the centre of backing off from a point *b*,

other than the centre *a*, as shown in Fig. 155. The thickness of the teeth remains constant, however much the faces are ground away, provided the faces are always ground radially. Mills of similar type are made for cutting the grooves in drills, reamers, and taps.

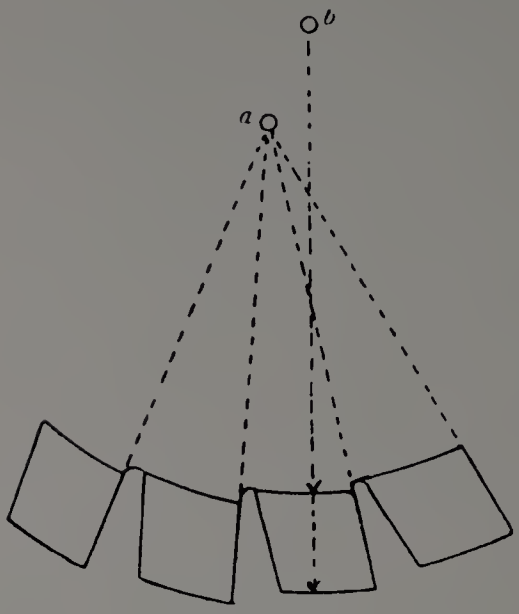


Fig. 155.

The lubrication of milling cutters is a necessity, cast iron being the exception. The heavier the cutting done, the greater the heat generated, with the consequences of injuring the cutting edges, and causing expansion of the cutters and of the work, and lessening the duty obtained. In the best practice there is no stint of lubricant, and as the oil is separated and used again, the cost is slight. The larger the cutters, the greater the need of ample lubrication, the oil being sprayed over from a pipe. A

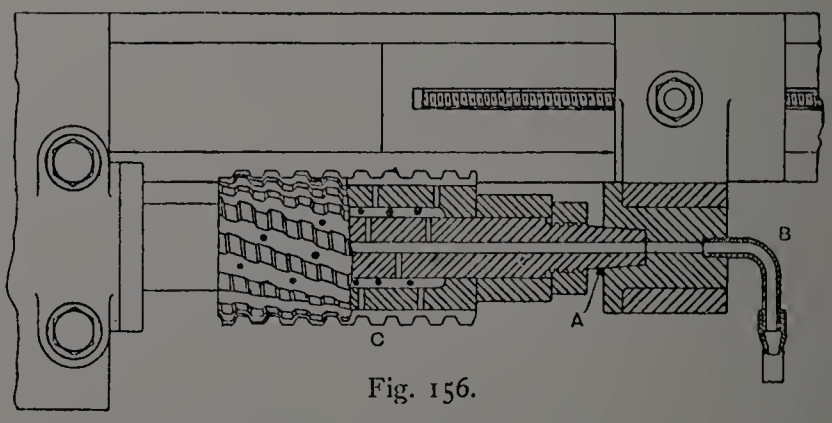


Fig. 156.

practice has been introduced, therefore, of lubricating from within, after the same principle adopted in drills. The Newton Machine Tool Works have a patent method of lubricating their slabbing cutters, shown in Fig. 156. A is the arbor, pierced with a hole for the lubricant, which comes in through the pipe B. C is the

cutter, hollowed to form an oil chamber. The lubricant flows through radial holes in the cutter body to the teeth. The teeth of these cutters, like those of the Ingersoll, are staggered to break up the chips.

Oil or soapy water is used generally for the lubrication of milled work in all metal except cast iron and brass. For occasional jobs, oil is often dispensed with; but where milling is practised as a system, it is employed in quantity. Then it is used far in excess of what would be required for lubrication simply, the work being flooded with it. The oil facilitates the formation of a smooth surface, and dislodges and swills the cuttings away. To the most complete machines an oil-pump and tank is affixed, by which an ample supply with little waste is secured.

Rough castings and forgings do comparatively little damage to single-cutting tools, but they injure the edges of milling cutters. Moreover, the milling of large surfaces is usually costly by reason of the first expense and maintenance of cutters, unless large numbers of similar pieces are to be operated on.

Since milling cutters are tools costly to make, and to keep in order, and since their efficiency depends on their truth, and on the keenness of their edges, it follows that it is not well to distress those edges except by legitimate duty. As metal which is non-homogeneous, and the scale of castings and forgings are very destructive to the keen edges or the cutters, in shops where a good system prevails, therefore, hard castings are annealed, and scale is removed by pickling, or by grinding.

CHAPTER XI.

Boring Tools for Wood.

The Bradawl—The Performance of the Gimlet Type—Its Drawbacks—Bits, and Augers—Centre-Bit—Its Unbalanced Action—Expanding Centre-Bit—American Screw Bits—Forms of their Cutters—Their Advantages—Counterboring—Improved Braces.

THE bradawl stands alone among boring tools. It forms its hole by a simple thrusting aside of the wood fibres. If, however, it is being thrust near the edge or end of a piece of stuff, the chisel edge should be set across the grain to sever it. Even the humble bradawl has clearance like a twist drill in the longitudinal direction, being smaller in diameter at the handle end than at the cutting edge.

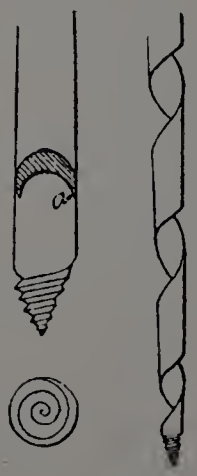


Fig. 157. Fig. 158.

All boring tools for wood, the bradawls and centre-bits excepted, are magnified gimlets, of the shell or of the twist type (Figs. 157 and 158). The two essentials in the formation of these little tools are the getting into the wood, and clearing the cuttings out. The screw at the end of each worms its way in, with, or without slight pressure; the entrance of the shell in the one, or of the twist in the other, cuts the fibres, which then creep up the hollow part of the shell, or up the twist, and so out of the hole—that is, they ought to do so; but it is in so imperfect a fashion that in deep holes in hard wood the gimlet has to be withdrawn once or twice, in order to get the cuttings out, or else considerably more pressure must be exercised as the hole deepens, and the friction increases. In hard wood the gimlet thus gets hot, and in larger sizes it has to be cooled by dipping it in tallow from time to time.

Nor are these the only drawbacks. Another lies in the fact that, as there is no provision made in these tools for nicking a circle round the hole to be bored, they cannot be depended on, either to bore holes true to centre, or round and smooth. This matters little in the gimlets, which are used mostly for the insertion of screws; but it does matter when bigger tools are built on patterns much resembling them. Such tools are the spoon, shell, and nose bits (Figs. 159, 160, and 161), and the half-twist bits. Of these, only the last named is capable of centring exactly; the spoon bits, and shell bits will only do so approximately, and the nose bit not at all. But the latter, once entered, tends to draw itself into the hole, and its withdrawal brings out the core by the lip or nose, *a*, and this therefore is a favourite form for making non-thoroughfare holes.

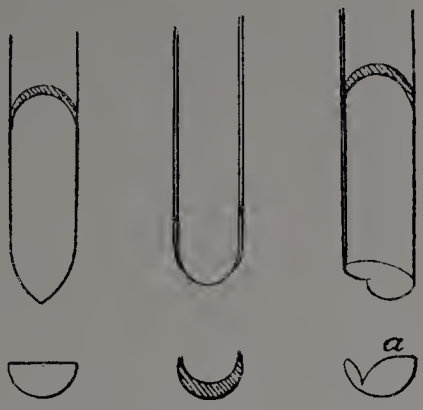


Fig. 159. Fig. 160. Fig. 161.

A shell auger (Fig. 162) is a magnified nose bit, but on account of its much larger diameter, the drawbacks of this form become most evident. In the first place, a shell auger will not start a hole neatly; hence a centre-bit or a gouge is generally used to commence with. The slope of the auger lip tends to draw the instrument into the hole under slight pressure, or often with no pressure at all. But the tool must be withdrawn from time to time in a deep hole in order to get out the core, and it also becomes hot, and has to be dipped in tallow. In hard wood, or in end grain, boring with an auger is hard work.

Fig. 162.

A drawback in all tools of the class just named is the absence of a nicking edge to precede the longitudinal cutting edges. The latter have both to cut the circle, and clear the hole. But the leading corner, which is not a good cutting edge, has to do the circular cutting. Such tools are therefore unsuitable for boring holes true and clean, and they are rough and inaccurate instru-

ments for deep holes. Hence the centre-bit (Fig. 163) takes their place for the first-named kind of work, where exact centring is necessary, and where smoothness of edge is required.

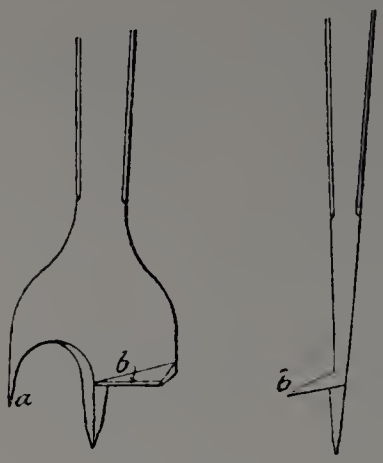


Fig. 163.

And yet the centre-bit is far from fulfilling these requirements in a decent manner. In its ordinary form it has no screw to start it truly, but a triangular tit instead; the nicker is single, and therefore unbalanced, and the cutter is single too. In small bits these unbalanced forces matter little, but when $\frac{3}{4}$ in. or 1 in. diameter is exceeded, then, especially when boring in hard wood, the bit turns jerkily, and penetrates slowly. There is nothing to help to draw the bit into its work save the cutter, and that being unbalanced, is as liable to dig in and hitch as to cut sweetly and smoothly. And further, there is no provision for guidance in the short body of the bit as there is in an auger, or a nose bit, or a shell bit, or a gimlet, or a twist drill. The only control exercised is that of the workman, who judges by the eye whether he is driving the hole plumb, or he gets a mate to take a sight, and tell him which way to lean the brace over.

Another drawback to the centre-bit is that it never bores to its normal diameter, but always larger—$\frac{1}{64}$, $\frac{1}{32}$, or more, according to its size. Another is that it is only suitable for boring plank way of the grain. In end grain, and diagonally it works with difficulty, and cannot be depended on to produce so straight and true a hole as in the plank way. In fact, in open, spongy, soft wood it is practically impossible to bore holes in end, or cross grain with this instrument. The screw centre-bit (Fig. 164), is but little better. The screw is better than the triangular centre-tit of Fig. 163, but the other drawbacks remain.

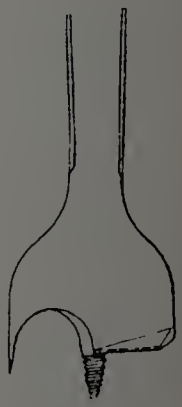


Fig. 164.

English woodworkers have to thank American invention for producing some of the improved forms of boring tools. The expanding centre-bit is a great deal better than the common bit,

not only by reason of its extensibility to suit holes of different sizes, and the exact size of holes to which it can be set to bore, but also because it centres itself exactly by a tapered screw, and the chip is broken up by a secondary nicker nearer the centre than the nicker which determines the diameter of the hole, thus reducing the labour of cutting. The shank of this bit is also divided into inches and quarter inches, so that the depths of holes being bored can be readily seen at a glance. None of the old bits contained even this provision, but bushes of various lengths, slid on the shanks, determine depths without measurement. But generally speaking, an expanding bit is not so valuable a tool as sets of solid ones in fixed standard sizes, and in the last named, the difference in the old and the new designs is most apparent.

Fig. 165.

The value of these solid bits lies in the fact that they enter their holes by accurately tapered screws, so ensuring exact centring; that they mostly have two nickers, and invariably two cutters, on opposite sides; that they have twisted clearance spaces of very large area, and generally of quick pitch, for the cuttings; and that they run parallel back from the cutting end for the greater portion of their length. They thus fulfil all the conditions which an ideal boring tool should do.

Fig. 166.

There are several bits now sold which fulfil these requirements in greater or less degree. They differ in the shapes of their lips, in the method of forming the twist, and in the amount of clearance left in the twists. Some have twists like those of the old-fashioned twist drills, and twisted augers; others resemble the turns of a screw-blade round a stem, a form which gives more clearance space than the other does.

Fig. 165 is an example of one kind—the Jennings—with a central screw, two nickers, and two cutting lips. This tool will bore with about equal facility in any direction of the grain, perfectly straight after it is fairly entered, and with very slight exertion on the part of the workman. Fig. 166—the Irwin bit—differs from it only in the form of the twist; the screw, nickers, and cutters being of similar

shapes. The cylindrical shaft, and the screw-like blade that form the spiral appear to give greater freedom of exit to the cuttings. Both, however, are very perfect tools.

In what are termed auger bits, and in the augers of this type the lips are usually turned up to help in getting out the chips (Fig. 167), and they smooth the hole partly made. There is the screw, and two cutters still giving balanced forces, and as these cut cleanly and sweetly, the wood is not torn by the absence of nickers. In some types the cutters are duplicated downwards and upwards. The ship auger (Fig. 168), is a very old form, which cuts at one side and bottom, and has a lip for withdrawing the core; some of these have a tapered screw, others are without the screw. In other bits, as the Irwin (Fig. 169) and the Gilpin or Gedge (Fig.

Fig. 167.

Fig. 168.

Fig. 169.

Fig. 170.

170), the cutters are gouge-like in form, and these cut very sweetly, while the truth in the hole is ensured by the screw, and the prolongation of the cutters upwards into lips.

Sharpening of these tools has to be done occasionally, as in the case of other kinds. But they can soon be damaged, and even utterly spoiled, by injudicious methods. The screws seldom require touching up, unless the points become broken off. If they do, a fine three-cornered file, as used for dovetail saws, is the proper one to employ. The shell of a gimlet or of a shell auger must not be filed on the outside, but in the hollow at *a* (Figs. 157 and 162). If sharpened on the outside they would soon be spoiled for cutting, because the edge would fall inside the circle of the diameter. Nicker and cutter must also be sharpened on the inside, as at *a*, *b* in Fig. 163, *a*, *a* in Figs. 165 and 166, and on

the inside of the lips in all cases. This preserves the diameter of the nickers unaltered, and prolongs the life of the cutters. If damaged by a nail there is no help for it but to file back, and take out the notch. Sweeter cutting results if the edges are finished with a small gouge slip, with which also the burr can be turned back.

These improved forms save a vast expenditure of muscle and time, to say nothing of the better results that are obtained. And here, too, as in so many other matters, specialisation leads the way. First, the manufacture of these tools lies in the hands of but a few firms. Second, the broad type is modified to an extent that was never dreamed of in the old days; for different craftsmen may be accommodated with special bits and augers varying in length, in twist, in shape of lips, and tang to suit their exact requirements. Moreover, the portable boring machine, which came in several years ago, designed for operating these auger bits, is, though simple, one of the most valuable woodworker's tools ever introduced. Instead of using the common brace, or operating the cross handle turned by hand, in gimlet fashion, it substitutes the crank handles and mitre wheels, giving power and speed in combination, so that it is but the work of a few seconds to bore through a foot of timber. And there is the certainty that the hole will be plumb, or to the exact angle to which the auger is set. In addition, too, there are the rapid adjustments of the machine.

The advent of these boring tools, both accurate, and rapid in action, has knocked out many of the old ones in shop equipments and men's kits. The centre-bits are common; but where they are retained, men generally have a set also of the superior kinds. The shell-lip augers are much scarcer than they were, the screw augers having largely taken their place. The price of the better tools, however, makes a man cautious how he uses them. They are suitable for new, clean timber; but in repairs, where nails may lie hidden to trap the unwary, the old cheaper tools are used, rather than risk injury to the lips of the expensive screw bits.

Every one knows the trouble of counterboring in wood. You have, say, a $\frac{1}{4}$ in. hole, and want to bore a $\frac{3}{4}$ in. one down to a certain depth. The safe way is to bore the larger first and the smaller afterwards. But then that is not always practicable nor convenient. But a centre-bit cannot hold in a hole $\frac{1}{4}$ in. in

diameter, and so it must be plugged temporarily to afford a centre for the larger bit. An American firm supplies little discs of soft metal to fill small holes of various sizes to take the screw of the large bit while boring (Fig. 171).

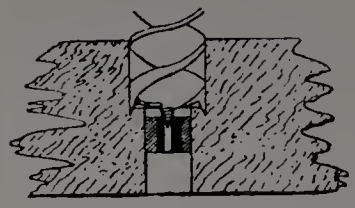


Fig. 171.

Along with these good tools better braces are available. The trouble with the old braces was manifold. A hole could not be bored in a corner where there was no room to turn the brace round, nor at an angle in a confined position. Bits from different makers did not fit alike. Friction was excessive. Now we have braces that have ratchet devices, so that a portion of a turn only is required to turn the bit, angular braces for boring at an angle, ball races to lessen friction; and loose jaws or chucks that accommodate themselves to tangs that vary in angle. Braces are shown in Fig. 256, p. 173.

CHAPTER XII.

Boring Tools for Metal.

The Drill—Variations in Flat Drills—Characteristics—Angles—Grinding—Twist Drills—Early Forms—Increase Twist—Constant ditto—Cutting Angles—Clearances—Effects of Grinding—the Point—Speed of Drills—Conditions which Affect Speed—Lubrication—Oil Tubes—Shanks—Enlargement of Holes—Reamers—Boring Tools—Pin Drill or Counterbore.

THE drill is one of the most curious among tools, its remarkable feature being the extremely wide range of forms in which it exists. The first drills were co-existent with Neolithic celts; the latest are still being improved on their immediate predecessors. None of the early drills could be ranked with true cutting tools; the later types are as truly so as are the chisels for wood and metal.

Consider for a moment the range of variation in drills. All must have some clearance, which will vary from half a degree to

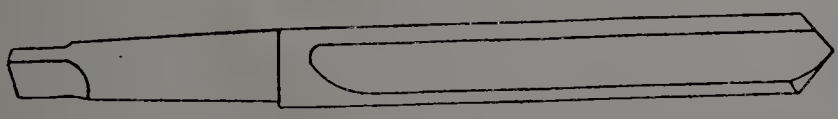


Fig. 172.

ten degrees or more. All twist drills have front rake, imparted by the angle of the twist in relation to the axis of the drill. But all straight-fluted drills (like Fig. 172), which do good work in brass, have no such angle, while the common flat drill (Fig. 173) has slight negative angle. Then, in reference to guidance, there is a great difference between the flat drill and the solid twist type. The getting out of the chips, which are crowded in the case of the flat drill, is neatly effected by the grooves of the twist drill.

The old flat drills did good work, as they do now in many shops, where they are retained for small work. They do it in

defiance of theoretical principles of tool formation. Cutting angles they have none, being scraping tools purely. The cutting-faces are flat, and nearly perpendicular to the faces being bored, so there is no front rake, or cutting angle. Generally, in fact, the cutting faces are ground off tapered, until the angle becomes greater than 90°. But they do their work well, for two reasons. The point is narrowed down, and the edge is well backed off, and where their action is nicely balanced on each side of the centre, these make up a set of favourable conditions that largely compensate for the one defect of a non-cutting front angle. These tools are not to be despised now in the drilling of powdery cast iron. Tough wrought iron and steel are the materials in which they operate least favourably, and only by large applications of oil will they do even a fair amount of work in these materials, without heating.

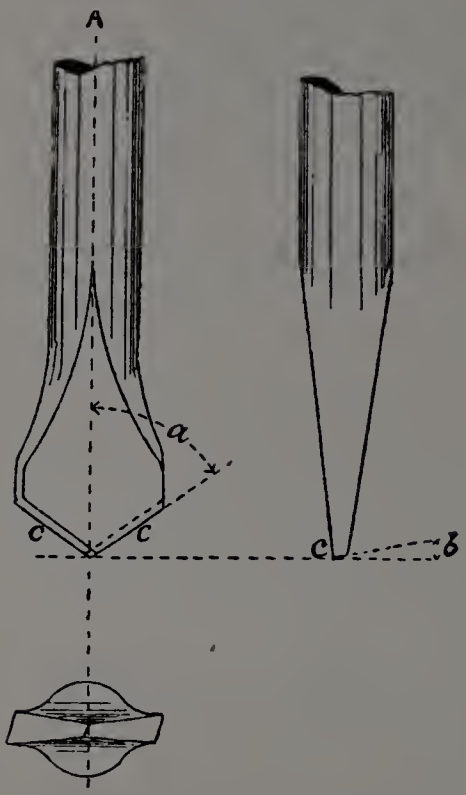


Fig. 173.

Because the common drill is destitute of top rake it is liable to become heated when fed too hard. For this reason hand feeding is best for drilling machines, the skilled workman's sense of touch, and sound being the best safeguard. Especially —and this applies to other kinds of drills—it should not be forced to its work at the commencement. It ought to be fed lightly at first, until the hole is fairly entered, and then a heavier feed may be put on for the completion of the drilling. Too heavy feeding causes a drill to spring, and run out of truth. It is easy to drill holes accurately with the flat drill. It is also very easy to drill them badly.

It might seem at first sight as if the most important points of design about the drill were the angles *a*, Fig. 173, which the cutting edges make with the centre or axis, and the angles *b*, which they make with the faces of the drill. But measure a

number of drills taken at random from a machine, or drawer, and the difference in the first will amount to perhaps 8° or 10° n those considered quite efficient, and doing good work. The angles *a* therefore need not be very precise. In fact, for working on thin plates of sheet iron and brass, the angle must needs be very obtuse, like Fig. 174, otherwise the point of the tool would be through the sheet almost directly, and the drill wobble, long before the effective diameter began to operate. Hence the angle *a* will vary in different drills between that shown in Figs. 173 and 174.

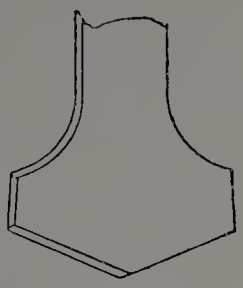


Fig. 174.

Of more importance is the angle *b*. It should not be very acute. It need not exceed 5° or 6° for iron and steel, though for brass-work it is often made as much as 10° or 12°. If the angle is too great, the drill chatters, and loses its edge more quickly than if kept within the limits named above. So that a difference of angle can be made with advantage in drills intended for different metals and alloys—less for the harder, tougher metals, greater for the softer, more crystalline materials. This angle *b* is called the angle of relief, or the "clearance" angle, its only function being to avoid friction between the portion immediately behind the cutting edges *c*, and the faces of the work being cut. While too acute an angle will result in rapid wear of the cutting edges, one too obtuse, while preserving strength, and durability of edge, will be productive of great friction.

Though some considerable variation is permissible in these matters, there is one detail which admits of no variation at all—the symmetry of the edges *c* about the axial centre A. Whatever the angles given to the cutting parts, the bevel of the edges must be exactly equal about the centre A, both in respect of radius, and of slope. In a drill of this kind the two cutting edges should each be doing an equal amount of work, and the stress due to drilling be divided quite equally between the two. This cannot be the case when the edges are unsymmetrical, which inevitably results in loss of efficiency, and sacrifice of good results.

In a drill ground unsymmetrically, Fig. 175, the radius A will regulate the diameter of the drilled hole, and not the diameter B, and the stress of cutting will be thrown wholly on the side *a*, and not on *b*. Or, if one edge is ground to a different angle

from the other, then the stress of cutting is thrown wholly on the edge with the larger radius, and the hole will run out of centre.

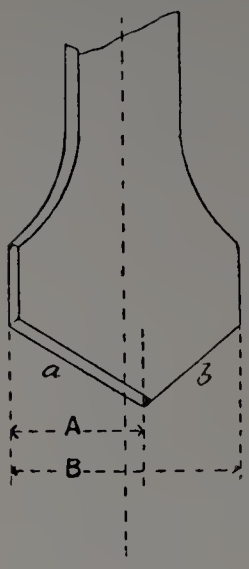


Fig. 175.

The departure from accuracy need not be great to produce these results. The exaggerated amount shown in the figure would not occur in practice. A departure from symmetry which could not be detected by the eye is sufficient to impair the efficiency of a drill.

If a drill makes 100 revolutions per inch of feed, that means that for each revolution $\frac{1}{100}$th of an inch of metal is cut away. If, therefore, there is a want of symmetry only to the extent of $\frac{1}{100}$th of an inch, the whole of the cutting will be thrown on the side with the larger radius.

A drill shaped unsymmetrically will not make a hole parallel, but will drill it tapered, the diameter being larger at the bottom than at the top. In fact, in some special jobs holes are drilled thus purposely, with a drill ground lopsided. No matter how rigid the shank of the drill, it will infallibly be pulled out of perpendicular by its malformation, and the slighter the shank, the more inaccurate will be the hole.

When drills run out, and cause holes to become located out of truth, which will happen sometimes even when the drill is correctly formed, due to carelessness in commencing the hole, or to the presence of soft or broken metal, then it must be corrected before the drill has penetrated far. This is done with a fitter's round-nose chisel. That side of the hole from which more material should be removed is chipped away, so that the drill shall commence again accurately.

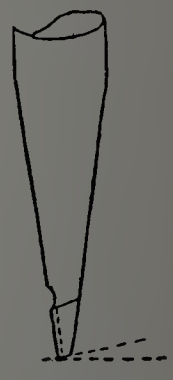


Fig. 176.

The application of rake to the front edges of the flat drill, Fig. 176, was a good idea, because by it a true cutting angle is obtained. But it gives a deal of trouble in practice, because the rake is soon lost by regrinding, and then re-forging and re-tempering become necessary, and so it seems better to get along with the non-cutting type.

The idea of the twist drill, simple though it now seems, passed

through a period of evolution before the modern drills were developed. The original idea appears to have been the twisting by the smith of a flat bar of steel of rectangular section, so giving, in regard to its method of formation, as well as ultimate shape, a real twist. Years ago there were plenty of these (Fig. 177), to be seen in engineers' shops, along with the flat lip drills. They embodied an idea which has been since brought to perfection, but they never supplanted the flat drills. They did not remove good cuttings like the modern twist drills, but broke them up, choking the hole. But, with few exceptions, the type has disappeared before the solid twist drill, although it is still preserved in the twist bits used for wood boring, which do excellent work. The weakness of this drill for metal-work lies in its excessive elasticity in small sizes, and therefore it does not fulfil the conditions of hard work so well as the solid twist drill does.

Fig. 177.

Somewhere about 1860, Sir Joseph Whitworth, and Mr Greenwood both made twist drills. Later, the Manhattan Fire-arms Company in America started their manufacture. The first drills failed because the cutting angles were too keen. Then Mr Morse followed, and by reducing the cutting angle very much, produced tools capable of doing good work. He also devised the grinding line, and the increasing twist.

The lips of twist drills are formed with true cutting angles, and in consequence of the circular form they are not so liable as the flat ones to run in their holes, nor bore larger than their own diameter; consequently the performances of these drills in respect of accuracy, and also of rapidity of work is in excess of that of common flat drills. Feeds may be increased 100 per cent. or more over those of flat drills; holes can be drilled so accurately that the drills will not afterwards fall out of the holes by their own gravity. Another advantage, too, is that the truth of a hole is more readily seen by using a twist drill. Before it has penetrated far, the fit of the drill in its hole indicates this.

For many years past two kinds of twist drills have been made —the Morse, with an increasing twist (Fig. 178) and grinding line; and those made with a regular twist, and without a grinding line. In the former, the cutting angle becomes more obtuse as

the drill wears down; in the latter it remains constant. In the former, the grinding line is used as an aid to symmetrical grinding; in the latter this depends wholly on the guidance of the grinding machine used, or on the gauging following hand grinding. Now, these cannot be both better, yet each claims supposed advantages over the other. It is rather remarkable that the question of constant twist *versus* increase twist in drills should still be an open one. The English-made drills are mostly of the first, the American of the second, class. In actual work there seems little to choose between the two. The points in favour of each are the following:—

Fig. 178.

In favour of the increase-twist type it is said that the chips get away more readily as the twist straightens out towards the shank end than they do from a constant angle drill. Against this, even if the statement is correct, is set the fact that as the drill wears back, the cutting angle becomes more obtuse, changing from the original angle to one of about 10° less when worn to a stump, and leaving the middle portion of the drill thicker.

The gradual thickening-up of the web of the drill from the point to the shank, which is done to render it stronger to resist torsional strains than one having a web of parallel thickness would be, is unfavourable to delivery of chips. In regard to the alteration in angle, it is well to remember that worn drills are well suited for drilling hard steel and brass, while they can be utilised, by re-grinding, for drilling slots and keyways. Further, by the time a drill wears nearly to a stump, it has well paid for itself.

Since in the constant-twist type the cutting angle remains unchanged, the makers of this type lay great emphasis on the constancy of the cutting angle during the life of the drill. There would be something in the argument if all metals and alloys demanded a constant angle. But as they do not, the supposed advantage seems to have been overrated. The angle of $27\frac{1}{2}°$ with the axis is a good mean, and that is a general one with twist drills when new. But a few degrees more is certainly not detrimental to good work, while in some cases it would be preferable to the lesser angle.

In the solid twist drills there are other points of variation. One of the curious facts is, that until within the last few years no attempt has been made to produce twist drills with different cutting angles to suit different kinds of metals—another proof that the maintenance of very exact distinct cutting angles for different metals operated upon, need not be insisted upon within a few degrees. That distinction, however, has been made in the twist drills (Fig. 179) of constant angle, formerly termed "T. & B.," and being of 10, 8, and 6 pitch respectively, meaning by these terms one turn of the spiral in a length of 10, 8, or 6 diameters of the drill.

Fig. 179.

Drills, as just remarked, are thickened in the webs towards the shank, to impart torsional strength. As this diminishes the clearance for the passage of the chips up the grooves, increase twist is imparted during manufacture by changing the speed of rotation of the drill on its axis as it is fed to the cutter which forms the groove, so altering the pitch, and compensating for the reduction in depth of cut. In the constant-angle drills made by the Morse Company the drill is rotated at a uniform speed; but the angle of the cutter is varied to widen the groove towards the shank.

There are three clearances in a properly-made twist drill: that from the point to shank, or longitudinal, that of the body, or transverse, and the clearance from the cutting edge—the backing-off. The first measures from about .00025 to .0015 per inch of length, dependent on size; the second about half a degree (Fig. 180, *a*, *a*). A slight width—"land"—is left before the clearances commence. The lip clearance is from 12° to 15°.

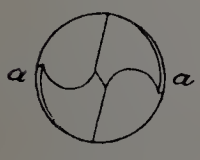


Fig. 180.

The angle which the cutting lips of twist drills make with the longitudinal axis of the shank is 59° or 60°, which gives straight cutting edges. The grinding lines, when such are used, are placed slightly to one side of the centre, so that when grinding is done by them there is

a certain angle at the point, which is the most efficient for clearance. Thus Fig. 181, A, shows the best angle of the point, being about 135° with the cutting edge; B one which is too keen, and C one with no angle, showing an absence of clearance.

The clearance of both lips should be exactly the same; for, if otherwise, one lip will tend to dig in more deeply than the other,

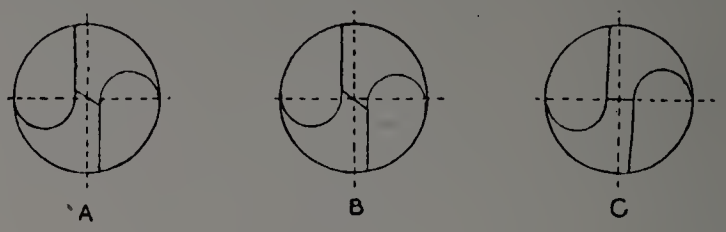


Fig. 181.

with the result that the torsional strain will not be equally balanced on each side of the centre, and this may break the drill.

If drills are ground by hand it is easy to test the amount of clearance given by means of a rule or scale (Fig. 182), setting the latter on each side in turn, and revolving the drill to measure the clearance in relation to the height of the cutting edges. A square having a scale marked on the blade will answer the same purpose.

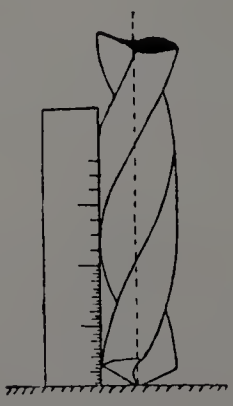


Fig. 182.

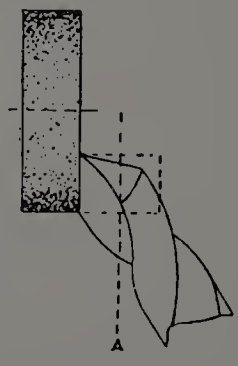


Fig. 183.

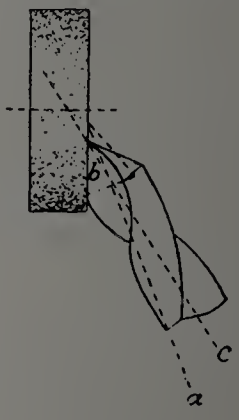


Fig. 184.

Two systems of grinding the clearance of the cutting edges of twist drills are illustrated by the diagrams Figs. 183 to 186. In Fig. 183 the drill is being revolved about a constant axis A while grinding, which gives a surface corresponding with a segment of a cylinder. In Fig. 184, the axis of movement of which is *a*, *b*, *c*, the revolution gives a surface corresponding with a segment of a cone. The

effect on the action of the drill is that of cylindrical, and conical rollers, respectively shown by the projections in Figs. 185 and 186, running in conical depressions. In Fig. 185, the clearance angle *a*, *b*, *c* of A is different from that at *d*, *e*, *f* of B, so that if the clear-

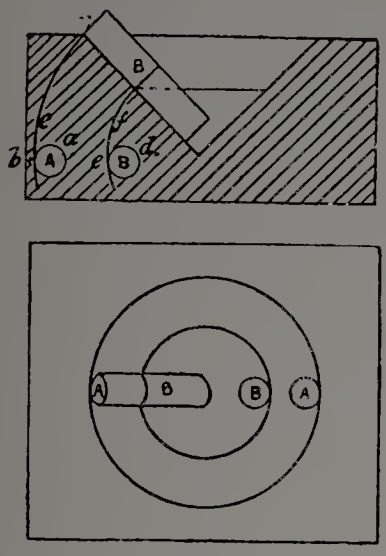


Fig. 185.

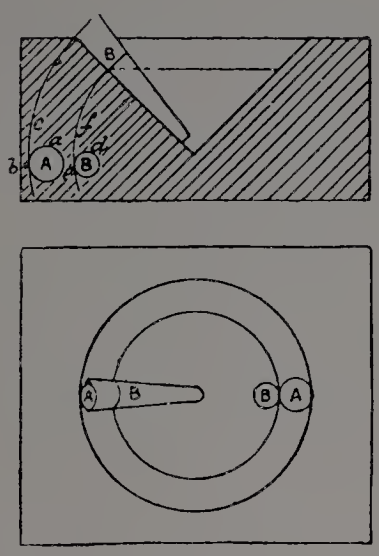


Fig. 186.

ance is right at the centre, it is excessive at the outside. In Fig. 186 the clearances at *a*, *b*, *c* and *d*, *e*, *f* are alike. This last, therefore, should give increased permanence to the cutting edge.

The Cleveland Twist Drill Company have investigated this subject in connection with a special apparatus, which recorded the best efficiencies of drills. The result is, that the correct form is found to be that produced by grinding to the segment of a cone whose axis is on the line *a*, *b*, Fig. 187, and at an angle *a*, *b*, *c* to the axis of the drill. Now it is evident that a cone may be steep or flat, and according as the angle which *a*, *b* makes with the face of the emery wheel is varied, will the steepness of the cone be lessened or increased. Where the cone is steep, and the point of the drill near the apex, the curvature at the point of the drill is greater than under the opposite conditions. The result is that considerably more power is consumed in driving the drill, as much as 20 per cent.

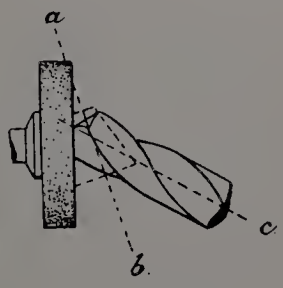


Fig. 187.

in one experiment. In the inverted "cone" formation the angle of clearance at the centre is greater than at the outside. But this must not be excessive in amount, or the edge will break out under heavy feeding.

If the drill point is a segment of the surface of a cylinder, the clearance angle is less towards the centre of the drill, and the corners at the periphery do not last under severe duty.

The cutting angle of the drill is fixed by the angle of the spiral of the flutes. As in other tools, practical considerations outweigh theoretical. A small angle, equivalent to a fine pitch of spiral, is best for cutting, but not for durability. These angles range in different drills from 18° to 35°, but the experiments of the Cleveland Twist Drill Company indicate that an angle of $27\frac{1}{2}$° with the axis is the best. This makes the spiral groove of all drills start at the point with a pitch equal to six diameters of the

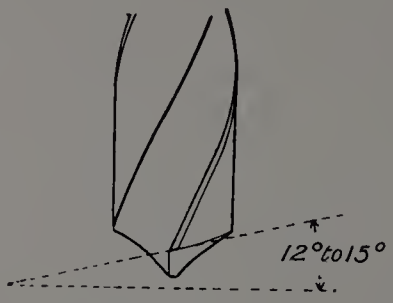


Fig. 188.

Fig. 189.

drill blank. The difference in the torsional stress on a drill does not vary much when the angle of spiral with the axis varies between 30° and 25°.

The clearance angle of the drill lip is fixed at the outer corners, where it should range between 12° and 15° with a plane perpendicular to the axis of the drill (Fig. 188).

One drawback to the form of the common twist drill is that the actual drill point, which gives an oblique connection (Fig. 181, p. 134) uniting the two cutting edges, like that of the flat drill, never cuts. It has simply to be ground into the metal by sheer force of feed. The only course open is to reduce that edge as finely as possible. In the flat drill this is done by thinning down the face. In a twist drill the web becomes thicker as the point wears back, and the evil, therefore, increases. The difficulty is minimised in drills of large and medium size by thinning down the point, as in Fig.

189, *a*, with corresponding increase in cutting capacity, without diminution of the thickness of the body of the web.

The speeds of drills are settled by judgment, and experience. If they are ground properly, and fracture at the edges, the speed may be increased, but the feed reduced. If the extreme edges alone suffer, that may be taken as proof that the speed is too high. The Cleveland Company recommend tentative speeds as follows:—30 ft. per minute for soft tool, and machinery steel, 35 for cast iron, 60 for brass, and a feed of .004 to .007 of an inch per revolution.

A remarkable fact is the great speeding-up which has been successfully accomplished in recent years. And this is not a question of tool angles. Even when these angles have remained unchanged, speeds have been increased 100 per cent. The explanation is to be found in the fact that drills are made better than they were, and that experience has shown how they are to be used to the best advantage. But no hard-and-fast rules are possible.

The speed of a drill is partly governed by the class of work being done, and by its surroundings, quite distinct from the nature of the material, because the generation and removal of heat are much influenced by these. A parallel case is that of a tool point gripped in a tool-holder, compared with a solid tool. The first is not capable of taking such heavy cutting as the second, because the heat is not carried away so readily. So in drilling, heavier cutting can be done with drills operating in large masses of metal than in small pieces. In the latter case, the best that can be done is to bring the small piece into close contact with a larger mass of metal, which will carry off the heat, either directly on the table, or in a vice, or resting on a large support. The worst condition is to have a non-conductor, such as wood, underneath the work being drilled.

Numerous are the apparently trivial conditions that affect drilling speeds. To drill a deep hole, from which the chips escape with difficulty, results in extra friction, and diminution of speed. To drill shallow holes, in which there is no trouble with chips, and in which the drill has many brief spells of rest when changing from hole to hole, is favourable to increase in speed. The nature of the lubricant used, quite apart from the quantity employed, is another factor. The frequency or other-

wise with which *the edge of the drill is restored by regrinding*, is another important element in speeding. So in a large degree is the quality of the steel in a drill—the degree of accuracy with which it has been manufactured, relieved, and ground; and almost as important as any condition is the amount of care and skill brought to bear upon the *hardening and straightening*. These reasons are quite sufficient to explain why differences in drilling speeds amounting to fully a hundred or more per cent. are found in practice.

THE SPEED OF DRILLS IN REVOLUTIONS PER MINUTE.

(Compiled by the Cleveland Twist Drill Company.)

Diameter of Drill.	Speed on Steel.	Speed on Iron.	Speed on Brass.
1/16	1150	1750	2000
1/8	575	1000	1200
3/16	425	700	900
1/4	285	450	800
3/8	210	325	500
1/2	145	220	375
5/8	125	180	315
3/4	105	130	250
7/8	80	105	175
1	60	90	145
1 1/4	55	80	130
1 1/8	55	70	115
1 3/8	50	60	105
1 1/2	45	55	100
1 5/8	40	50	90
1 3/4	40	48	80
1 7/8	35	45	65
2	30	45	55
2 1/8	28	40	50
2 1/4	28	38	45
2 3/8	26	35	40
2 1/2	23	32	40
2 5/8	23	32	35
2 7/8	20	30	35
3	20	30	35

As illustrative of the fact that the work which a tool is capable of doing is very much a question of material, the case of the manufacture of the twist drills themselves may be noted. When the steel rod used for the drills has been selected as nearly as practicable of the same quality, and been annealed as nearly as

possible alike, it has been found that a tool which will turn as many as twenty-five blanks 1 in. in diameter and 11 in. long, taken from one lot, without regrinding, when turning a lot of blanks from another annealing, the tool might have to be re-ground for each blank. This was not either a question of hard veins or non-homogeneity of any kind in the steel, but simply one of degrees of hardness of the annealed material.

Fig. 190.

These facts explain why drilling speeds vary so much, and for these reasons tables given are only valuable as approximate indications of what should be expected of drills working under average conditions.

The Morse tables are those which are generally accepted as giving the best results. They are not the highest nor the lowest. A table of especial value, compiled by the Cleveland Twist Drill Company from memoranda furnished them from about five hundred of the best American firms, is lower. On the contrary, the practice of the Brown & Sharpe Company is much higher than the Morse tables. An abstract of the Cleveland table is given on the opposite page. Feeds are from 95 to 125 revs. per inch. The Morse feeds are $\frac{1}{4}$ in. drill, feed per revolution .005 in.; for $\frac{1}{2}$ in., .007 in.; for $\frac{3}{4}$ in. .010 in.

A good deal of drilling is now being done with tools of high speed steels, with efficiencies from three to five times greater than this table gives.

The ordinary drill is a tool which is difficult of lubrication in deep holes; and this is rendered more so by the accumulation of chips, which clog and hinder the action. A well-formed twist drill drives the cuttings out; but with flat drills, the occasional removal of the drill, and the clearance of the chips with a wire is often necessary in deep holes.

Fig. 191.

There are three types of drills in which the difficulty of lubrication is got over in three different ways. In one, oil tubes are let into grooves in the drill body between the grooves (Fig. 190). In another, oil grooves are drilled in the drill body (Fig. 191). In the third, used only in turret lathes, a single large oil groove runs down the drill.

Modern arrangements, too, for pumping oil under pressure are used in the drills in question. The oil pressure fulfils the double function of keeping the drill cool and of forcing out the chips. The pressure at which oil is fed varies in practice from 40 lb. or 50 lb., to 200 lb. or 300 lb. on the square inch.

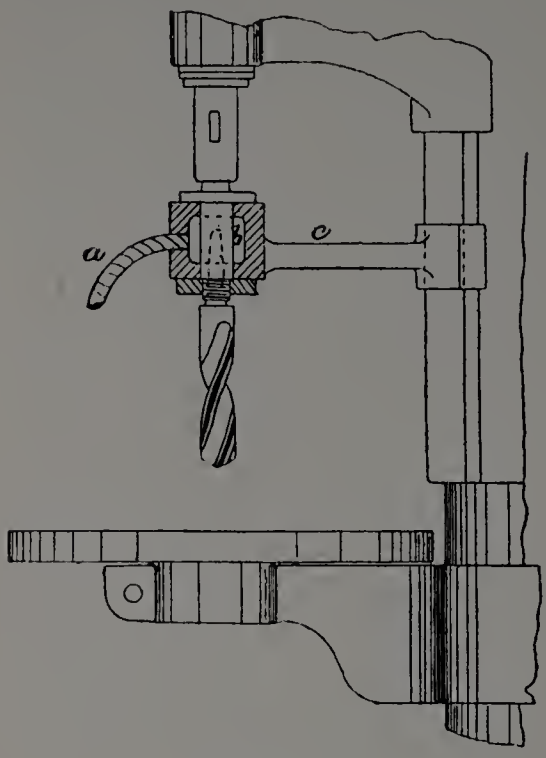


Fig. 192.

These drills are costly as yet, but they are an indication of probable future developments. As regards relative merits, holes in the solid seem preferable to tubes, which may work loose.

In making the twist drills with oil holes in the solid, the blanks are first rough-turned, and then at that stage the oil holes are drilled. The drilling is done with a fixed drill, the blank revolving. Subsequently, the blanks go to the smithy, where they are heated, and twisted, until the oil holes take the same twist as the grooves to be afterwards cut. Then the turning is finished, followed by the grooving.

Fig. 192 shows how lubricating drills are used on a machine. A flexible tube *a* conveys oil from the pump to an oil box *b*, in which the collet which holds the drill revolves. The oil-box is held by the extension arm *c*, to prevent it from partaking of the revolutions. In turret lathes for fixed drills, other simpler arrangements are adopted.

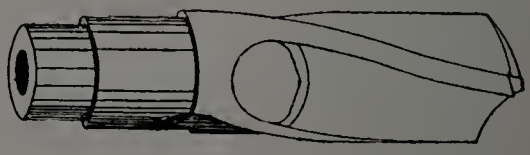


Fig. 193.

Fig. 193 shows a lubricating drill used for long holes. It is screwed to a metal tube of the required length, through which the lubricant passes, and the cuttings escape.

The best results in drilling are obtained in gun-barrel work. In these the speeds are much in excess of those in the ordinary machine shop. The feeds, however, are exceedingly fine, and these results would not be possible if the drill itself were revolved. The drill is stationary and the work revolves, and the chips are driven out by a flood of oil.

The drill in Fig. 194 has the oil hole. The point of the drill in Fig. 195 is stepped, to break up the chips, and so facilitate

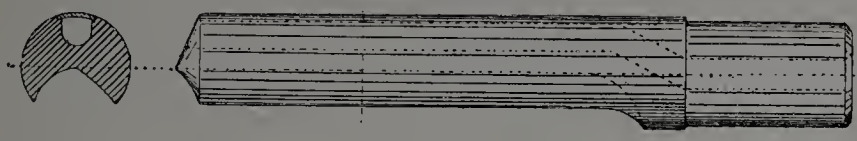


Fig. 194.

their removal by the oil, which was run through at the rate of two gallons in a minute.

It is a rather striking fact that in the latest twist-drill making, hand-filing in the lathe is resorted to in order to produce exact gauged results. The reason is that the steel used is of a hard, high-carbon class, and even though the tool is set the same, the drill blanks do not all come out the same size. The limit is a quarter of a thousand under size, and nothing over, and this is the fine dimension obtained by hand filing, and hand gauging. This includes the filing taper for clearance lengthwise.

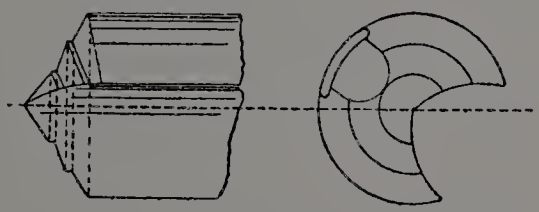


Fig. 195.

Twist drills are ground on the point only, after hardening. Though the hardening bends and warps them, this is corrected by hand work. The drills are heated in a gas-flame just sufficiently to permit of bending without drawing the temper, and squeezed under a press. They are tried on a perfectly level surface, the light underneath the drill showing whether it is true or not. A test deflection is used to try the degree of hardness of each. If the drills are too hard they break; if too soft, they bend.

The taper-shank drills predominate over the straight-shank drills. The latter can only be used in small sizes, or under about $\frac{5}{8}$ in. size, because drills of larger diameter cannot be driven by a

chuck for their heaviest duty. The taper shank, with a flat at the end for holding, renders the drill rigid under any cutting. Fig.

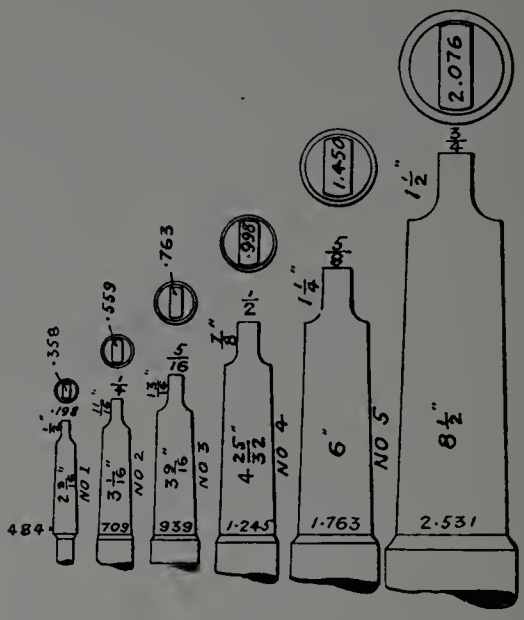


Fig. 196.

196 shows at a glance the proportionate sizes of the Morse standard taper drill shanks.

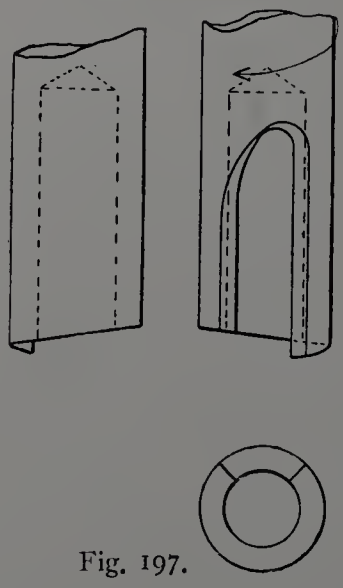


Fig. 197.

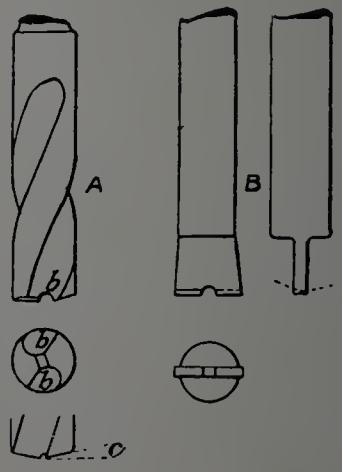


Fig. 198.

Fig. 197 shows a hollow drill, with no front rake, made specially for drilling the tube plates of locomotive boilers. It is hollow, and removes an annulus of metal.

Fig. 198 shows two drills not used for boring holes, but for slot drilling, hence the reason of the forms of their cutting edges. They revolve simply, while the work is traversed beneath them, and down feed is not imparted, except during the interval between the traverses. A performs precisely the same operation as B, but illustrates the utilisation of worn-out stumpy twist-drills by suitable

Fig. 199.

regrinding of the cutting edges. These can be used with advantage, for they cut faster and more sweetly than the usual form B. The end is ground flat, and then a clearance angle *c* is imparted behind the cutting edge *b*. The lowermost figure shows the end of the drill turned partly round, to show the clearance angle *c*. The small concavity ground at the centre of A and B separates the two cutting edges, and the revolution of the drill obliterates the ridge left by the concavity directly it is formed. Other forms are

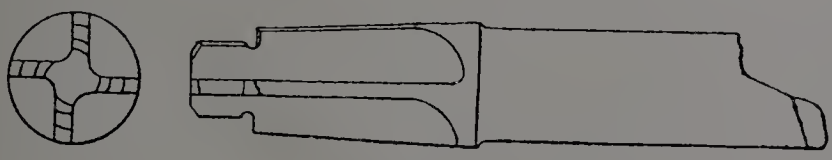


Fig. 200.

sometimes given to slot drills; but these are suitable for cutting keyways and cottar-ways.

Fig. 199 illustrates a very special form of drill used in turret lathes. The tool is of the notched, or staggered type (see page 73), the object of which is to increase its efficiency, by breaking up the chips. Fig. 200 follows and smooths the holes to the exact taper required, operating thus like a reamer, a class of tool to which we now give attention.

No drills work so accurately as to be depended on to produce holes to perfect gauge fit. If a hole has to be drilled, so that a turned, or ground pin shall fit it with absolute accuracy, it is

necessary to finish the hole with a solid tool of the exact diameter of the hole required. This is much more necessary when there are several holes in line. The true drills cut holes in solid metal, which distinguishes them from the reamers, rymers, or broaches, and boring tools, which open out holes already drilled. Their use is this:— Since it is practically impossible to drill holes in pieces of work through which, when assembled together, turned bolts or pins have to pass and fit closely; the holes are therefore drilled $\frac{1}{32}$ in. or $\frac{1}{16}$ in. less in diameter, and after the work is assembled, they are finished to full size with reamers.

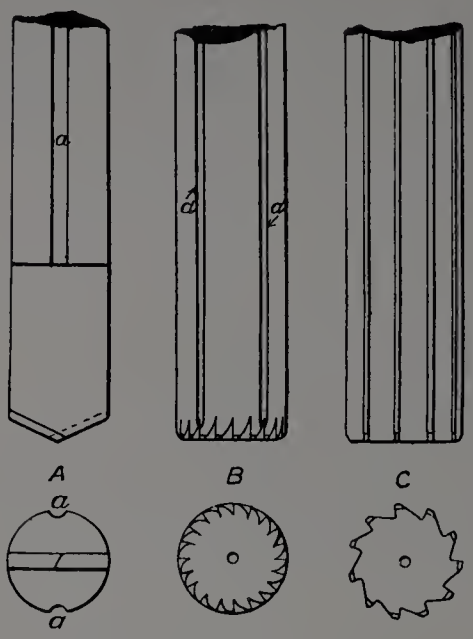


Fig. 201.

A, Fig. 201, is one form, the principal recommendation of which is that it is easily made in the shop. It is a solid turned bar, flattened at the end, and ground like a common drill. The fine cuttings and the lubricant pass up the grooves *a*, *a*. B is a much superior form, the nose of which is serrated into a number of fine cutting points, which remove the metal in very minute chips, the latter passing up the grooves *a*, cut in the solid shank. The teeth of the rose reamer are either cut on a convex edge or a flattened one. In neither case do they remove much material. C is better adapted for rapid cutting. The grooves are milled, and pass large quantities of chips readily. The tools shown are solid reamers. Hollow tools, Fig. 202, with teeth similar to C, are made to fit on arbors of standard size, a single arbor thus taking reamers of various diameters. There are also reamers made, the cutting edges of which are movable,

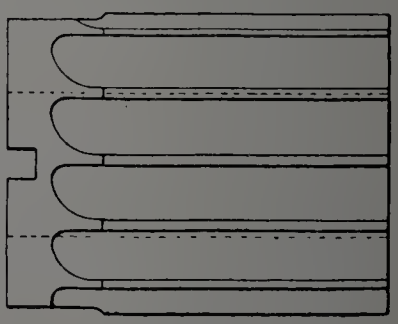


Fig. 202.

and so adjustable to different diameters, some examples of which follow :—

The Rogers reamer is of simple construction, involving no screws or nuts. The blades, Fig. 203, are fitted into dovetailed

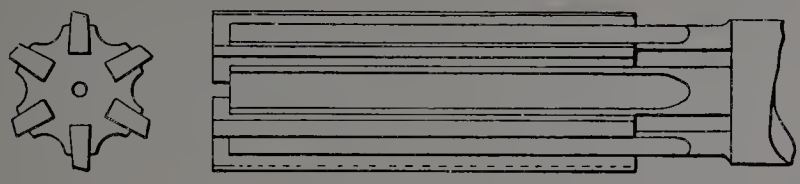


Fig. 203.

grooves, which are inclined, so that the act of driving the blades up the grooves expands the cutting diameter. After driving has been done to the limit of the length available, fresh blades are inserted.

The Morse reamer, Fig. 204, is adjusted by means of a tapered

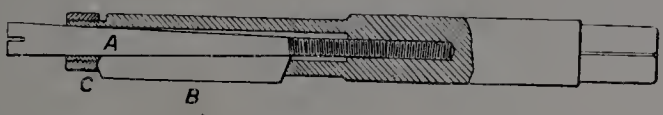


Fig. 204.

plug A, which is screwed into the body of the reamer, as shown, and acts against the undersides of the cutters B, of which there are several. The nut C serves to tighten the whole fitting when the desired adjustment is obtained, and unless this nut is previously loosened the blades and plug cannot be moved.

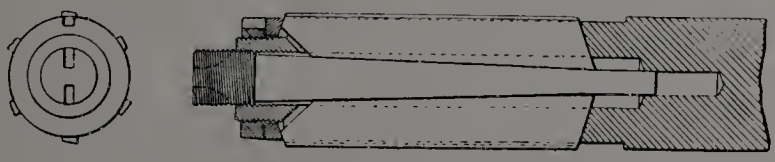


Fig. 205.

Another form of the Morse reamer is shown in Fig. 205, where instead of the thread being cut on the small end of the tapered plug, it is located at the big end, as seen. A special spanner embraces this end, and engages in the slots cut therein. Otherwise the principle is exactly the same as Fig. 204, a locking nut being provided similarly.

Another reamer which has blades running in inclined grooves is shown in Fig. 206. The adjustment is effected by screwing up the tapered nut, and securing it with the lock nut, so that the blades are firmly held.

Another expanding reamer, Fig. 207, has blades A which rest upon a circular nut B, having grooves cut in it to take the blades, the latter being inclined as shown. The ends of the blades are held by hooking them over a sleeve. Moving the latter along the body causes the blades to slide up the grooves in the nut B, and so cut larger, the nut C being the means of sliding D. To lock the blades firmly when adjusted, a cap E is screwed against them, and locked with a nut behind, F.

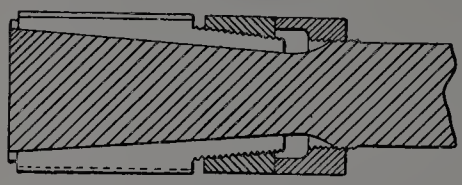


Fig. 206.

The fluted reamers cut down their sides. The number of flutes varies mainly with diameter, but different ideas prevail with regard to the number of teeth which a reamer should have, whether even or odd, and also with regard to the shapes of the grooves.

The objection to the reamers with an equal number of flutes is that each tooth is balanced by only one set opposite to it, and

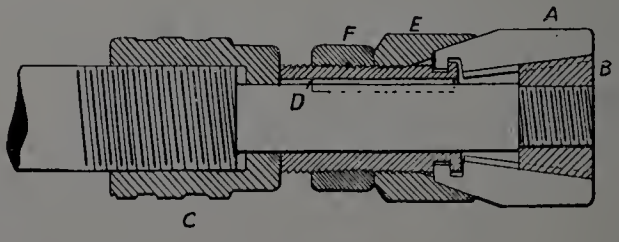


Fig. 207.

therefore if a hole is out of truth, one tooth only will cut in that direction; but if the spacing is unequal, each tooth will be balanced by two on the opposite side, which gives a better chance of true work. Sometimes an even number of teeth is spaced unequally to produce the desired result.

The objection to equal spacing lessens, the more closely the teeth are pitched, because as the latter become closer, the hole is filled up better. But close pitching is open to two objections.

One is that the cuttings do not get away so freely, the other that grinding is not so readily done.

In grinding reamers, generally the axis of the emery wheel is parallel with that of the reamer. Then it is easy to see that close pitching would not permit the wheel to clear the next succeeding tooth. The use of small wheels is objectionable, because, forming a sensibly concave face, they weaken the cutting edge. It is a rule that the largest wheel available should be used, in order to leave a face practically flat. The Pratt & Whitney Company even recommend that a convexity be imparted to the ground face. Fig. 208, A, illustrates the eccentric method of grinding, by comparison with B, the usual; A therefore resembles the "formed," or relieved cutter (see page 118, Fig. 155).

Reamers are mostly now made with radial teeth in milling cutter fashion in preference to the older convex grooves of the tap style. The latter act more by scraping, and the amount of front rake changes with grinding. The faces of the teeth are generally radial. Undercut faces tend to dig into the work, especially in brass. Sweetness of cutting is further secured in some cases, as in milling cutters, by setting the flutes spirally instead of parallel, between which practice is divided. Sometimes the spirals are left-handed, so that they will have no tendency to draw into the work.

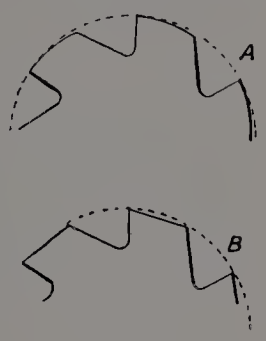


Fig. 208.

The reamers are a connecting link between the drills and the boring tools. The use of a boring tool presupposes the formation of an initiatory hole with a drill. This is true of the reamer also. But the amount of metal removed by the latter is usually slight, while that taken out by boring tools is often large in quantity.

Fig. 209 is a boring tool used for cutting holes in sheet metal when the holes are too large in diameter to be done with the common drill. It is formed on the type of the pin drill. A hole is first drilled in the plate of the same diameter as the end A of the bar, the bar being either parallel or turned down. A cutter B is wedged into a slot in the bar, and is adjustable for radius. Owing to the length of the radius, and the weakness of the cutter, heavy cuts cannot be taken without chattering. It is to lessen risk of the tool point digging in, and chattering, that the tool is

cranked backward, and thickened just behind the cutting point. These tools are sometimes made solid—that is, the cutter and shank are forged in one. Fig. 210 illustrates another type of boring tool which is used for the same purpose as the previous

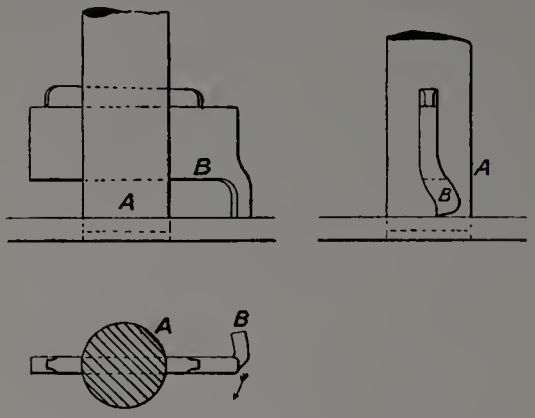


Fig. 209.

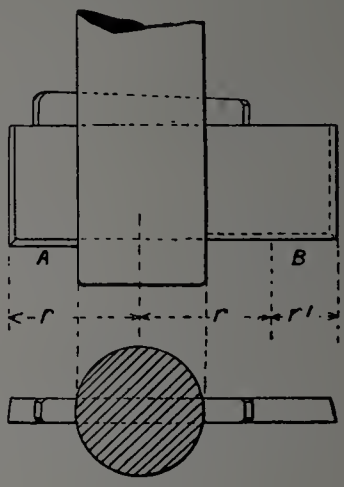


Fig. 210.

one, only that it is better suited for boring deep holes. The range of the cutter B in Fig. 209 is limited in depth; but the cutter in Fig. 210 will bore a deep hole as well as a shallow one. To lessen the stress upon the cutter the work is divided, and the stress nearly balanced between the edge A and the edge B. A

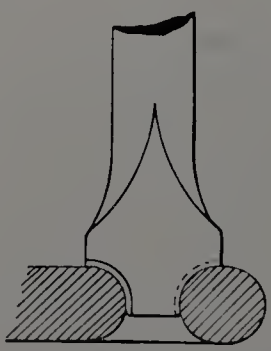


Fig. 211.

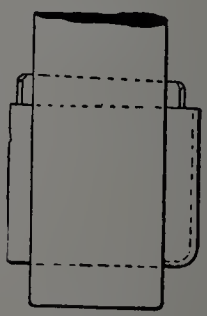


Fig. 212.

stands a little below B, and operates first on a area of metal of radius r; B following, operates on an area r^1. It is a useful tool for cast as well as wrought iron.

In these tools, though a hole is first drilled to receive the end of the boring bar, the work done is not an enlargement of an

existing hole, but the removal of an annulus of metal concentric with the drilled hole. With the true boring tools, however, the work done is the direct enlargement of a hole already cast or drilled nearly to size. In this sense, Fig. 211 may be considered related both to the reamer and the boring tool. It is flattened like a drill, and cuts like a boring tool. It is used for skimming round the edges of the eyes of small crane hooks, to prevent the rope from being chafed. One-half the hole is first smoothed, then the hook is turned over to do the other half.

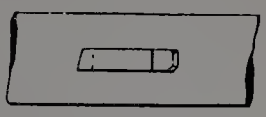


Fig. 212 is a common form of tool used for miscellaneous boring. It has one cutting edge only; many, however, have two. Boring tools of this general type are made either like Fig. 212, used without the guidance of a bush, the stiffness of the bar being sufficient to keep them steady during cutting; or they are steadied with a bush fitted into a hole in the table of the drilling machine. Bushes of the same outer diameter, but of different bores, are fitted into the table to suit boring bars of different diameters.

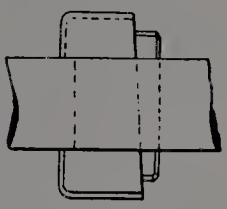


Fig. 213.

Fig. 213 shows double-ended cutters in boring bars, on which the changes are rung in many ways. In boring large holes, a head of cutters is used, fixed, or traversing on a boring bar. A good deal of information relating to these and other forms of boring tools is given in the author's "Engineer's Turning."

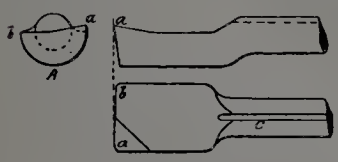


Fig. 214.

A considerable amount of boring of a rough kind is done with a flat bit, but it is not adapted for precise work because it lacks rigidity, and wobbles, following the lead of a roughly cored hole. The bit is rendered more accurate by blocking it with wood, of nearly semicircular section on each side, so filling up the hole. These tools cut by their leading corners chiefly.

The D bits, Fig. 214, operate truly, whether used as drills or as boring tools. The radius of the tool A equals that of the hole which has to be drilled or bored. The cutting point *a* has both top and front rake, and the edge is clear of the work at *b*. The lubricant passes along the groove *c*, usually through a bit of copper

pipe. Such bits will drill holes up to about 3 in. diameter. In large bits the actual cutter is a separate piece of steel screwed into the body. The latter forms three parts of a circle, ensuring ample guidance. The cutter can be moved forward as the cutting end becomes worn by regrinding. A lip is formed at the cutting

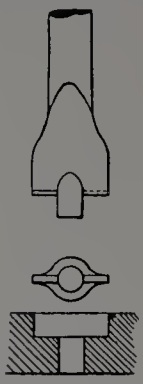


Fig. 215.

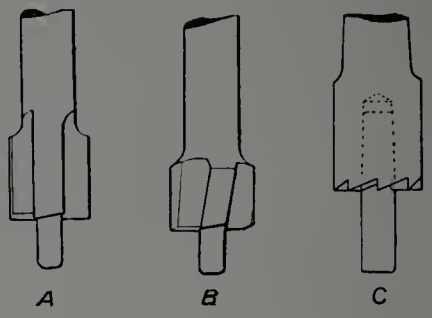


Fig. 216.

edge for the purpose of dividing and breaking up the wide shavings, and so facilitating their removal.

Figs. 215 and 216 illustrate arboring, or facing tools used on the drilling machine. They resemble pin drills in fitting into holes already drilled. Fig. 215 is a solid arbor; in many the arboring cutter is wedged into the bar. After a hole is drilled, the boss on the metal round the hole can be faced off with these tools at the same setting, with the certainty that the face will be at precise right angles with the bore. These are, therefore, used very extensively on drilling machines. Fig. 216, A, shows one that acts as a scrape, B one that has front rake; in C the side teeth are absent, and the pin is inserted with a taper.

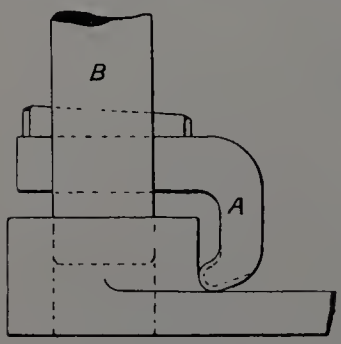


Fig. 217.

Fig. 217 is a bossing tool. The advantage of its use is that lever bosses can be turned without resetting the work, either on the drilling machine, or in the lathe. It comprises a cutter A wedged in a bar B, the bar being of a diameter to fit the hole bored in the boss. The same cutter will do for a wide range of bars. The rate of downward feed is proportional to the diameter, and rate of revolution of the cutter.

CHAPTER XIII.

Taps and Dies.

Taps and Dies a compromise—Difference between these, and cutting with Lead Screw—Relation between a Tap and its Screwed Hole—Initial and Final Diameters—Sets of Taps—Operation of—Relieving—Cutting Angles—Dies—Balance of Guidance and Cutting Power—Size of Master Taps, or Hobs—Action of Dies—Notches—Guide Screw Stocks—Dies used in Screw Machines—Echolls Taps.

IN the dies and taps the difficulty has ever been to combine good cutting capacity with adequate guidance, and with reasonable permanence of edge. One condition is opposed to the other, and every tap and die is a compromise between these antagonistic features. We will consider the principles on which all screwing tackle is based.

A screw is a wedge, or inclined plane wrapped around a cylinder, and is therefore formed by the composition of two uniform rectilinear motions, one moving around, and the other along the cylinder. By varying the relative rates of these motions, screws of various pitches are struck, and this variation is the function of the leading screw, and change wheels of the screw-cutting lathe, and of the chasing lathe, and its hobs. In each of these we have positive guidance, and the truth of a screw cut by either of these methods depends on the truth of the guide screw, or the hob made use of. These methods are properly reserved for cutting screws of considerable length, the accuracy of which must be maintained within narrow limits. Some lathe guide screws are true within one-hundredth of an inch on lengths of from 4 to 6 ft. Such accuracy would not be possible in screws cut otherwise than by the aid of an accurate master, or guide screw. But here the function of guidance is separated from that of cutting, and there is no analogy between a thread cut with a pointed tool controlled by a lead screw, and a thread cut by

means of taps or dies drawn into or over the work by their own lead, or by the control of a wrench or a stock held in a workman's hands. For while the functions of guidance, and control are separate and distinct in the first, in the second they are combined in one tool—a distinction which is very important, since in the first a narrow edge only is cutting, and in the second the cutting edges encircle, or are encircled by the work.

Observing first the action of a tap, we notice that good results have to be obtained by the use of theoretically bad tools in consequence of the interfering influence of the depth of thread.

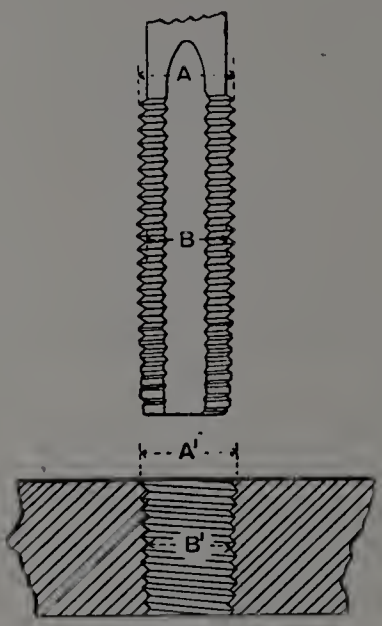


Fig. 218.

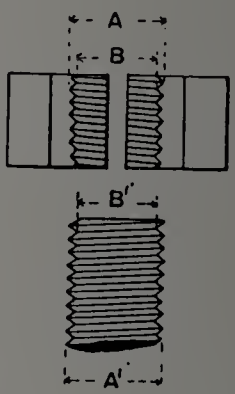


Fig. 219.

Thus in Fig. 218, in which the relation between the tap and its screwed hole is shown, this difference is apparent. The diameter A has to coincide with A^1 at the termination of the cutting of the thread, and B with B^1. But at the commencement of the cut, the drilled hole into which A has to work its passage is of the diameter B^1. Similarly in Fig. 219, though A coincides with A^1 when the thread is finished, yet the bottom diameter B of the thread in the dies has to embrace A^1 —the diameter of the thread at its point—before it can cut its way down to B^1. Hence there is want of coincidence in the diameter of the screwing tools, and of the work done by them; and further, there is a change in

angle from root to point, because the angle of a screw thread changes with its diameter, the pitch remaining the same. (See Fig. 220, where the difference in angle is shown by the slant lines *a*, *b*, projected, that to *a* representing the point, and that to *b* the bottom of the thread.)

Fig. 220.

The design of all common screwing tackle is complicated by these differences in initial and final diameters, and in varying angles, and for this reason no screwing tackle, as ordinarily used, is more than approximately correct. Such tackle is in greater or less degree a practical compromise, a striking of averages, rendered necessary by the fact that taps and dies, the diameters and angles of which do not change, have to cut threads, the diameter and angles of which change constantly from the first starting of the thread to its completion. This is brought home most forcibly in cutting square-threaded screws; but the same thing exists in vee threads, though not in so pronounced a manner. In screws of fine pitch, the difference between the angles of root and point is so slight that it has little practical effect upon results, but as screws increase in pitch, the difference has to be reckoned with, and provided for.

Taps are designed to cut internal threads gradually, and by this means the difficulty as regards difference in diameter is rendered practically nil. Three taps, which constitute a set, are called respectively a "taper," or "entering"; "middle," or "second"; and "bottoming," or "plug." The taper tap (Fig. 221, A) has only four or five full threads left at the top; they are entirely cut away at the bottom, leaving the diameter there the same as the bottom of the thread. From thence the depth of thread increases uniformly until the full depth is reached, at four or five turns from the top. The middle tap B has all its threads full except the last four or five, which are partially tapered, and the plug tap C has all its threads full. When a deep blank hole has to be tapped,

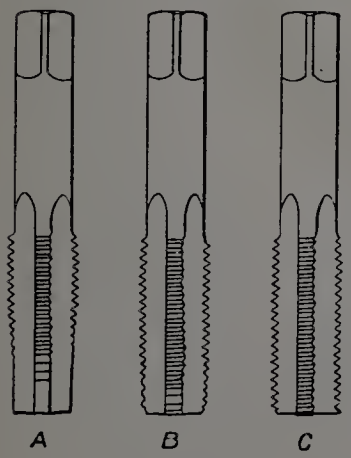


Fig. 221.

the first tap is entered, and allowed to cut as far as possible; the second follows and cuts as far as it can go; and the third finishes, cutting right down to the bottom. If a thoroughfare hole has to be tapped, the first or second tap alone will suffice, going right through. By the use of the three taps the transition from the small to the large diameters, with the corresponding alterations in angle, are effected with a minimum of friction and squeezing of the material.

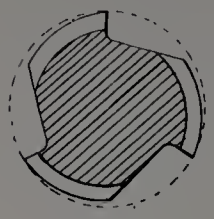


Fig. 222.

But it is evident that if the cross-section of the tap were that of a complete circle, there could be no leading edge to cut, and no relief for the following surface. Hence, in Fig. 222 the section of the tap threads is not concentric, but they are backed off, and the leading or cutting edges are thereby rendered better able to penetrate, wedge-like, into the body of the material, on the application of much less force than would be required in the absence of the backing-off. Also, the following surface clears itself of much frictional contact, entering into a clear space cut for it by the leading edge. This backing-off, or relieving is very pronounced in the entering tap, and very slight in the middle and finishing taps, because the bulk of the material is removed in the first operation, while the last two smooth down inequalities left by the first.

The tap, therefore, when properly formed operates as a true cutting tool, and yet it is much less favourably shaped for cutting than single-edged tools, to which it bears no outward resemblance. The amount of backing-off which is possible is extremely slight. If this were given in considerable amount, the tap would lack guidance, though its cutting capacity would be improved. And while a common turning tool has a top rake of several degrees, the tap rarely has any, but the leading or cutting edges generally point to the centre, making an angle of 90° with the surface of the work. Sometimes the faces are sloped slightly, to give a keener angle, but it is usually found that the edges are weakened thereby, and do not endure so long as those which have radial faces. Taps of the triangular and square sections, as sometimes made in small sizes, cannot be ranked with true cutting tools, because the angles are too great; but being small, there is little friction, and so they perform their duties fairly well, and these

are the types on which larger taps were once made. Fig. 223 shows the hob or master tap used in cutting dies.

Turning to the dies, we note also the due balancing of similar qualifications—namely, guidance, and cutting power. Without the first, drunken and wavy threads would result; in the absence of the second, the material would be squeezed, and swaged up in the act of removal. Referring to Fig. 219, the want of coincidence in diameters at the commencement of striking the thread is apparent, an evil, the effects of which cannot be modified in the case of solid screw plates, but which is masked by the smallness and shallowness of the threads in screws below $\frac{1}{4}$ in. to $\frac{3}{16}$ in. in diameter. The difficulty is surmounted in screws of larger sizes by the employment of adjustable divided and movable dies, set in a screw stock, whereby minute differences in diameter are effected as the threads become deepened. There is, however, the same difficulty as regards difference of *angle* at the commencement and termination of the thread. Also there is the difference in *curvature*, due to change in diameter, to be taken account of. Let us see how these varying elements receive embodiment and compensation in the dies usually constructed.

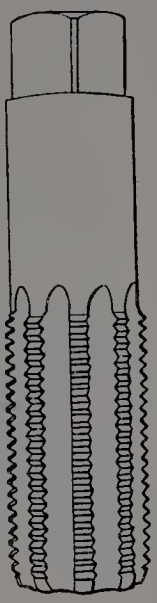


Fig. 223.

Every one knows that dies are cut with hobs larger in diameter

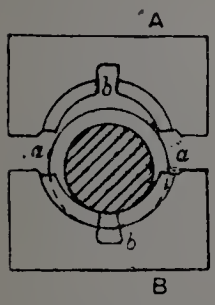


Fig. 224.

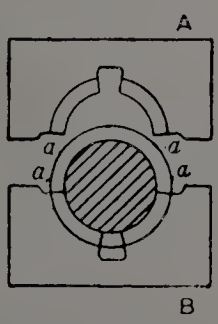


Fig. 225.

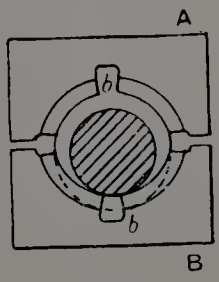


Fig. 226.

than the screws which are to be cut by the dies. The diameter of the hobs (Fig. 223) is generally larger by the depth of one thread, and sometimes by two threads, than that of the screws to be cut. Figs. 224 to 226 show the relative situations of the

dies round a bar at the commencement and termination of a cut, A showing a die when about to cut, and B the same when the thread is finished. It is seen at once that the cutting power of the dies is due to difference in curvature, for if it were possible to use dies which would embrace the bar closely at the finish, like Fig. 225, they could not cut at the finish, but only squeeze. But in Fig. 224 the edges cut at the commencement, A penetrating before the body of the die thread can touch, that body being thrown off the bar by reason of the curvature, and therefore furnishing an angle of relief behind the points *a*. Presently the curves of the dies, and those formed therewith coincide for a moment or two, and then the action is purely squeezing, until the internal corners *b*, *b* effect a slight penetration into the material, and so acquire a cutting capacity, which increases until the thread is down to its proper size, the curved portions again being thrown out of contact, as at B. Also, since the dies are symmetrical, they cut equally well, whether turned right, or left handed.

The figure shows an average curvature, and notching. But there is a limit to each of these. Sometimes dies are cut over a hob two threads deeper than the screw to be cut. Sometimes the notches cut away a larger proportion of the circle. Each of these modifications has an important influence on the results. If dies were cut over a hob of the same size as the screw to be cut, they would lose guiding power entirely, because the merest corners would touch at *a*, *a*, Fig. 225, and the tendency would be to start drunken, or wavy threads, or else to cut concentric grooves; in short, they lack "leading." When they are cut over hobs of two threads deeper, they have abundance of lead, because the curvature coincides with that of the bar at the commencement, but they squeeze at the beginning, while at the finish the corners *b*, *b* are so sharp that they cut with great avidity, increasing as the thread becomes finished (Fig. 226). Again, if too much of the circle is removed by the notches, leading power is diminished, and little or nothing is gained for cutting; and if, on the other hand, there are no notches at *b*, *b*, the dies could never cut anything smaller than the hob on which they themselves were formed, because once the curvatures of the dies and the screw threads which they cut coincided, they could never get below that. But with the internal edges *b*, *b* coming into

play, the thread diameter can be reduced below the diameter that corresponds with the dies themselves.

Clearly, then, in whatever manner the threads are cut in the dies themselves, their action is necessarily imperfect at some stage of their operation, and this is borne out by the fact that when cutting threads by them, frequent reversal of the die stocks is necessary to ease the work—a practice which is never necessary with the chasing tools held in a turret lathe.

The guide screw stocks used to-day are the survivals of early attempts made by eminent mechanicians, to overcome the evils of the enormous amount of friction, and heat which the common dies generated, and their squeezing and scraping action, which prevented the formation of threads of accurate pitch. For the earliest of these we must go back to 1826, when a Mr Peter Keir effected an improvement which was the forerunner of others. By introducing a cutter into a groove sunk in a die, the thread roughly formed was deepened by a true cutting action. In 1828 a Mr Jones devised an improved form in which the cutter was clamped upon the face of the screw stock. In France several attempts were made to improve on the screw plates by devising screw stocks with movable guides, and movable cutters. Mr Bodmer invented a guide screw stock with vibrating or oscillating dies, but though ingenious, and to all appearance perfectly efficient, it never came into general service. This was probably due to its rather complicated character. The well-known guide screw stock, and dies of Whitworth, used everywhere to-day, was the first really successful attempt to strike a suitable mean between the controlling and cutting actions. In these stocks (Fig. 227), there is one die which acts by guidance only to the other two which do the cutting. By separating the functions of the fixed guide A, and movable cutters B B, practi-

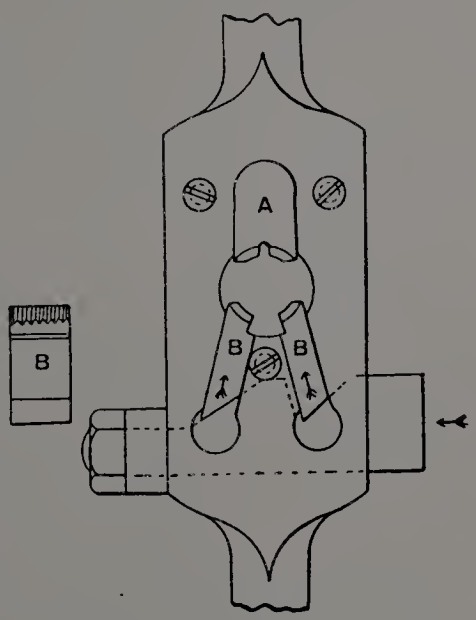


Fig. 227.

cally perfect threads are secured, while variations can readily be made in diameter for threads of different sizes, and the effects of wear are not apparent. The dies are cut from a full-sized master tap, that is, one twice the depth of the thread larger in diameter than the screw to be cut, and they are therefore of the same curvature at the start as the blank which they have to cut. The fixed die cuts at the start, but it is nearly inoperative afterwards, except as a guide. Only one movable die cuts at a time, the other operating when the motion of the stock is reversed. The cutting faces are set radially, so that they always point to the centre of the blank, as a lathe tool does. They are re-sharpened by grinding on the faces.

In an earlier die-stock of Whitworth's the principle of letting the cutting predominate, resulted in the guidance being insufficient. But that, with little modification, anticipated the dies and chasers of to-day, in which the guidance is so slight that they cannot be used in a die-stock, to be adjusted over its work by hand, unless a guiding bush is used, though they give the highest results in a screw machine, in which they cannot get out of truth diagonally in relation to the work being screwed.

In the dies used in screw machines, the cutting action is very keen, so that in all screws of moderate size, one traverse is sufficient, unless fine limits are desired. The results are obtained by using narrow cutters, by which the guiding action is diminished, so that instead of length of thread, preponderating over notches, as in Figs. 224 to 226, the notched portions in solid dies, and the spaces in die heads are much greater than the thread surfaces. This, with the better leading afforded by the machines, and the improved lubrication, better facilities for sharpening, with other matters, have rendered tools which are imperfect theoretically, very serviceable in practice.

The Echolls patent taps (Fig. 228) differ from the ordinary ones in this:—That every alternate tooth is omitted, leaving a space which permits of the clearance of the cuttings without frequent reversal of the tap, this result being shown in Fig. 229. It is claimed that the resistance to tapping is from 30 per cent. to 50 per cent. less with these than with the common ones. Fig. 228 shows the taper, the plug, and the bottoming taps.

Expanding taps, and taps with inserted cutters are used to a moderate extent, but not much in ordinary shop practice.

Threads can be cut with dies of the opposite hand. This is a mechanical curiosity of no practical value. It depends on the size of hob over which dies are cut. It could not be done with dies cut over hobs two threads larger than the screw, it can with

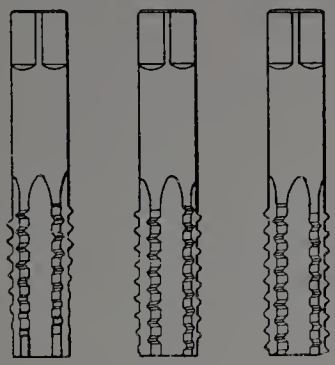


Fig. 228.

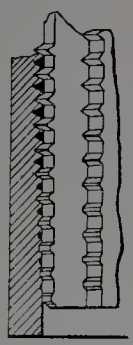


Fig. 229.

those cut over hobs of the same size as the screw, and in which the extreme points only come into contact with the screw blank at the beginning of the work. At this time, therefore, the dies will yield to pressure turning them with a left or a right hand lead, and once started, the dies will follow the lead.

SECTION IV.

PERCUSSIVE, AND MOULDING TOOLS.

CHAPTER XIV.

Punches, Hammers, and Caulking Tools.

The Punch—Spiral ditto—Taper of Punch—Burr—Various Punches—Drifts—Hammers—Varieties of—Force of Blow—Mallets—Caulking Tools—for Plates—for Pipes.

THE punch is an annular shearing and detrusive tool having angles of 90°, or, rather, very slightly less, by from $\frac{1}{2}$° to 1° due to the clearance of the body. The power required to operate a punch is so great that the practical limit to thickness of the plate punched is the diameter of the punch itself. Spiral punches have been designed to produce a shearing cut; but they have found comparatively little favour, because they are less easily kept in order than the ordinary types.

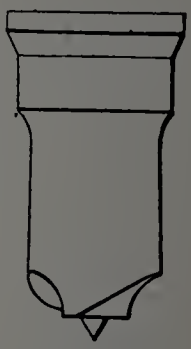


Fig. 230.

Kennedy's spiral punch (Fig. 230) has been used with good results. Mr Webb, of Crewe, who first gave it an extended trial, found that the strength of the same steel plates after using the spiral, and the common punch, equalled 63,929 lbs., and 58,579 lbs. respectively, a difference of 5,350 lbs. in favour of the spiral tool.

The circumference of a punch is very small by comparison with the length of shear blades. The action is so violent that the severed edges are left torn and ragged and fibrous, and metal in the immediate vicinity is ruptured with minute cracks. If a clean shorn surface is required, this can be produced in thin work only, because the shearing force required for thick plates is so great that

no chisel-like tools of the purely cutting type would endure it. These last come in when wire is to be severed, in which, though the apparent action is that of shearing, there is no shearing cut at all; nor is it necessary, because the area severed is so small. The cutting angle of these is much the same as those of the tools for turning wrought iron.

Fig. 231 shows the common form of punch, and its bolster, tapered to allow the burr to fall through.

A rule for the angle of the punch, and clearance between punch and die, is to draw an acute angled triangle with a 2 in. base, and 12 in. high, and on that draw a line across where the width is equal to the diameter of the punch, and another between

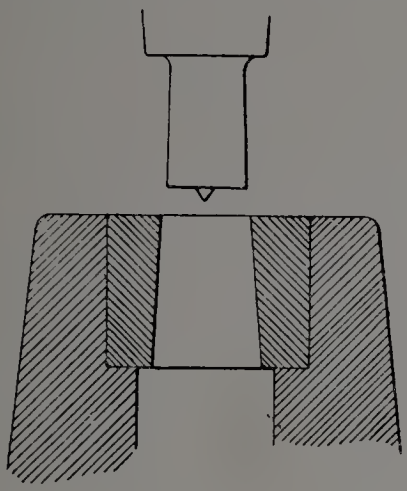


Fig. 231.

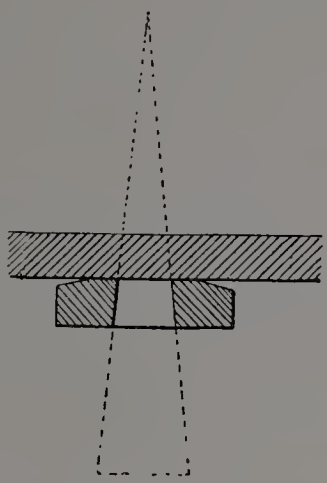


Fig. 232.

at a distance equal to the thickness of the plate to be punched, and there obtain the diameter of the hole in the die.

Another rule for the taper of punches and their dies, which was arrived at as the result of experiments, is as follows (Fig. 232):— Draw a triangle having a base 1 in. in length, and two equal sides meeting at a distance of $5\frac{1}{4}$ in. These will give the angle, on which at the height corresponding to the diameter of the punch, set off the latter, and below it the thickness of the plate to be punched. Below this, the size of hole of the bolster, the diameter of which, therefore varies with the thickness of plate. Its taper must be at least as much as that given by the triangle.

The common punch has been responsible for many cracked plates, hence the reason why, in good work, no riveting is per-

mitted to be done as the plates leave the punch, but reamering is insisted on. From twenty to twenty-five years ago this was a burning question in the plating and boiler shops, since which time, practice has settled down either to punching, followed by reamering; or drilling, the latter being generally adopted in boiler work, while both methods are adopted in bridge and girder work.

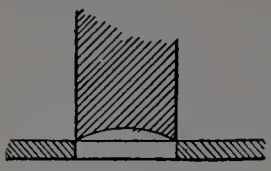


Fig. 233.

The punching, or burr produced by a common punch is never so thick as the plate from which it is driven. It is always concave, and convex on opposite sides. It has, however, the same specific gravity as the plate, which shows that the material which represents the difference between the contents of the hole and that of the punching has been squeezed into the plate. A zone, or annulus round the hole is thus stressed, and cracked, and suffers in consequence. This zone only extends about one half of a millimetre, so that in reamering out a hole, say, from $\frac{1}{32}$ in. to $\frac{1}{16}$ in. larger, the stressed metal is removed.

Fig. 234.

The form of punch shown in Fig. 233 has been proposed in order to obtain a true shearing cut, instead of a detrusive one, but it has not found much favour.

Multiple punches are arranged in machines in numerous designs, and fill a large place in the economical manufacture of bridges and girder work.

Fig. 235.

Among the minor punches are those having special functions, as the following:—The centre punch (Fig. 234) used for popping centres and centre lines on engineers' work. The brad punch, used by woodworkers for driving the heads of nails below the surface, so that they may be covered and concealed by stopping. The small hand punch employed by packing-case makers for forming the nail holes in the hoop iron bonding. The punches of the *repoussé* worker, which do not make holes, but indent the surface of the metal sheet, so producing the designs required.

Fig. 235 is a centre punch for special service, its function being to set in the centres of rivet holes through holes in a plate already punched to another, the holes in which have to match it.

Drifts are used in association with the punches for enlarging holes, and for pulling holes in plates into alignment with each other. The first named are allied to the moulding tools. Fig. 236 shows the drifts used for pulling holes into line. Fig. 237 is a drift employed for the enlargement and smoothing of holes already made in smith's work by punching. Fig. 238 is one of a more special character used under a power hammer, by which flanged rings are produced from annular discs. In both these last it is necessary to support the work on a bolster in opposition to the drift.

Fig. 236.

Few tools vary more greatly in form than the hammers. Every trade has its own special forms, and some, as boiler makers, and tinsmiths, include a large number.

Fig. 237.

With the exception of the claw hammers, the claw of which is used for withdrawing tacks and nails, scaling hammers, and a few of that class, both ends or panes of hammers are used for percussive purposes. The panes are of circular forms, large or small in diameter, or they are oblong, or hemispherical in form. When oblong they are long pane, as when the longer portion runs in the same direction as the handle; cross pane when they run across. They are ball pane, when of more or less hemispherical form. Variations occur besides in the lengths of hammer heads, some being short, others long, some straight, others curved. In every case the design is suited to the functions of the hammer. Nothing comes by chance. Thus the hammers of the boiler-maker and the patternmaker are both long, so that they may get down into angles, which short hammers would not reach. The shoemaker's hammer is broad, for working on leather soles. Other hammers, such as some of the smith's sledges, and miners' hammers and planishing hammers, have both faces alike broad. Others combine an axe-like edge, with a hammer pane, as in some quarrying tools.

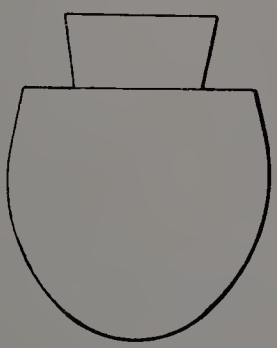


Fig. 238.

Fig. 239, A, shows the most familiar form in which the

hammer occurs. It is just a carpenter's tool for general service. B is a better form, because longer, and the narrow pane is more

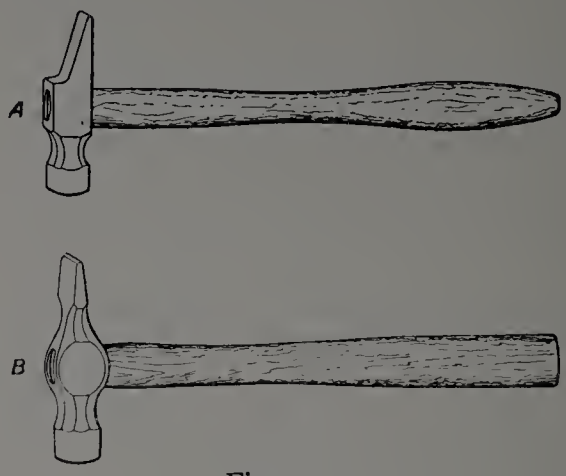


Fig. 239.

serviceable for reaching into the deeper parts of work for tapping or driving brads. The group in Fig. 240 comprises engineer's and boilermaker's hammers, A being cross pane, B long pane, C ball pane. D, E, F, are ordinary boilermakers' hammers, used chiefly in rivet work, G is a hammer in name only, being strictly a percussive chisel used for detaching the scale from boilers. Fig. 241 is a group of sledges, A straight pane, B cross pane, C the common double-faced sledge, D ball pane, E is a round-faced sledge used by boilermakers for flanging tubes. Fig. 242 is a smith's monkey, slung with a rope by the eye A, and swung back in an arc of a circle, and released by a rope round the eye B. It is used for upsetting work laid horizontally.

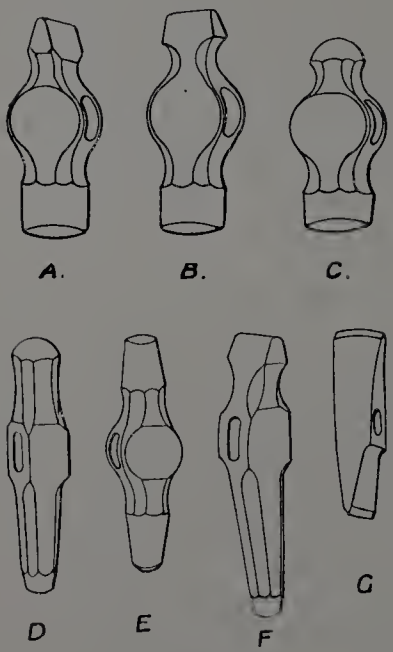


Fig. 240.

Hammers are fitted with handles of medium length usually, but the sledges are exceptionally long to permit of their being swung. Wedges hold the handles in a doubly tapered eye, or in

some cases the hammer head is prolonged into straps which embrace the handle through which they are riveted.

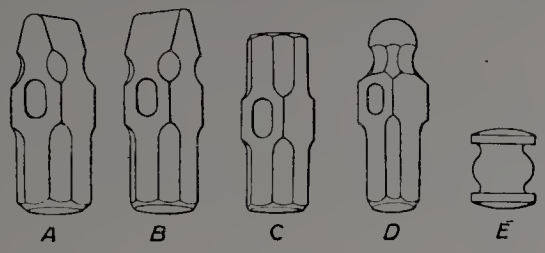


Fig. 241.

Fig. 242.

Hammers are fitted to power-operated machines, both of the gravity drop, and steam types.

Hammers are made of solid steel, or of iron, steel-faced. They are sold by weight, which in different kinds may range from a few ounces in hand hammers, to 14 lbs. in sledges. The force of a blow delivered is governed by the mass of the hammer, and the distance through which it is swung. The latter is under the control of the workman. Its amount is capable of calculation, and is given in text books, but in practice it is a matter of mechanical instinct, and judgment. The net result is that of developing a force for a short time equal to that produced by the continued pressure of a steady load; and is the same problem as that of the steam, or drop hammer, compared with that of the hydraulic press.

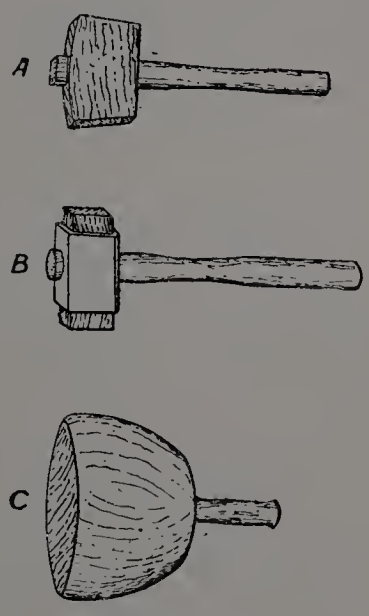


Fig. 243.

The mallets, Fig. 243, A, are a special form of hammers, the

reason for their use being the bruising effect of steel-faced hammers on tool handles of wood. One exception to this is a wooden mallet C, used on a stonemason's steel chisel. Mallets are bonded in steel, B, in some cases. Fig. 244 is a boilermaker's

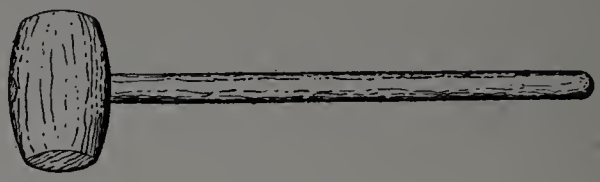


Fig. 244.

mallet, used for levelling plates, without risk of bruising them. The handle of a mallet is fitted with a taper, the larger end of which is outward, so that the head will become tighter, instead of flying off by centrifugal force.

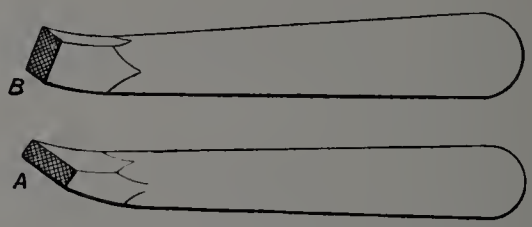


Fig. 245.

Midway between the steel hammers and the wooden mallets are the lead, and copper hammers of the fitter, and machinist, plain cylindrical, or barrel-like in outline. These are used for the same objects as the mallets of wood, namely, to avoid bruising metal work by the act of driving.

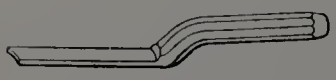


Fig. 246.

Caulking tools belong to the percussive class, because they are actuated by hammers. Their function is mainly that of burring up the edges of steel and iron riveted plates, in order to render them tight against water, or gases, hence the edges of the tools are roughened up, or serrated (Fig. 245). The difference in A and B is that A is narrow, and does not operate on the entire thickness of the edge, but only on that portion adjacent to the adjoining plate, while B is as deep, or deeper than the plate

thickness, and is used for broad finishing. Both are varied also, in being made convex on the lower face to suit curved plates. These are hand tools, but the types are embodied in pneumatic caulking tools, which deliver several hundreds of blows in a minute.

Fig. 246 is a caulking tool of another kind, used for driving the yarn, and lead used in caulking the socketed and spigoted joints of water, and gas mains. These are made both straight, and curved in section, as shown in the figure.

CHAPTER XV.

Moulding, and Modelling Tools.

Two Great Groups—That which is Related to Percussive Tools—Smiths' Flatters, Fullers, and Swages—Their Co-relation to the Fibrous Characters of the Materials—Trowel Group—Plasterers' Tools—Moulders' ditto—Cleaners—Sleekers of Various Sections.

THERE are large numbers of tools which are related to the percussive group, because many of them are actuated by hammer blows. This group includes on the one hand tools which operate on iron and steel at a red heat, and on the other those which produce, or finish the contours of moulding

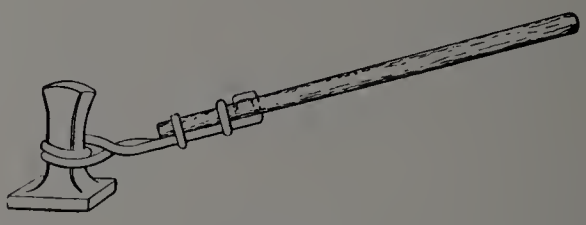


Fig. 247.

sand, modelling clay, masons' mortar, and plasterers' materials. They are employed in many trades.

Taking first the group which moulds the forms of iron and

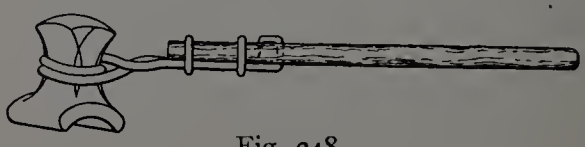


Fig. 248.

steel while white, or red hot, the value of these depends on the viscous or fibrous character of these materials. None of these tools, for example, would be of any service on cast iron, or brass. The representative of the class is the smith's flatter (Fig. 247), and

its allied form, the set hammer. Curved tools developed from these are the hollow swages (Fig. 248), and the fullering tools (Fig. 249, A and B), each of which occurs in several dimensions, and many curvatures. A special adaptation is the rivet sett C, the working face of which is an exact counterpart of the tail of the rivet which it finishes. Special forms of fullering tools used on steam hammer work—hence having long handles—are shown in Fig. 250. A is of circular section, and is used for fullering down bars by a succession of shallow concavities. B is used to fuller bevelled faces to a definite angle, and C is employed for making scarfed ends for welding. These tools are laid upon the work by the smith, and struck by the tup of the hammer.

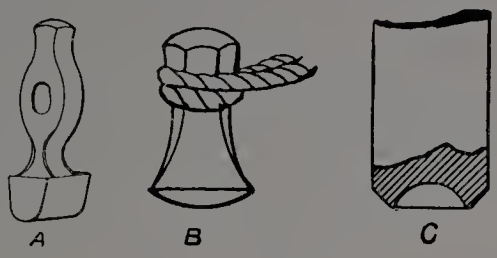


Fig. 249.

This is merely a typical representation of a group which is numerically large. Neither of them cuts, or removes any material, but simply moulds it into shapes which are nearly or quite the counterpart in form of the acting portion of the tool.

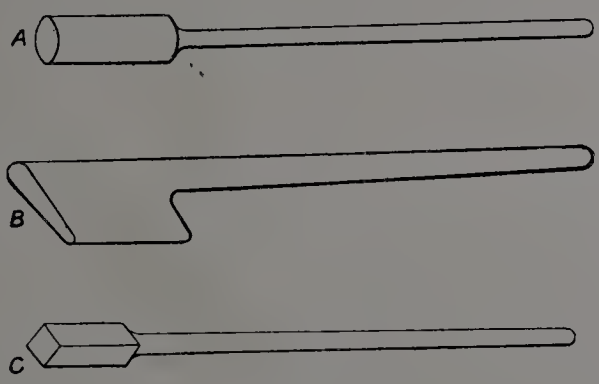


Fig. 250.

So little suffices to sever fibre, and the weakening effect is so great, that when it is necessary to reduce the area of a bar, or to bend it, or to groove it, sharp tools are never used to set down the metal. The effect of nicking a bar with a sharp tool is to sever the grain, and cause a crystalline fracture. This is seen in the method adopted in smithies in cutting off bars. The latter are laid on the anvil chisel, and nicked all round with the sett, and struck

with a hammer, so forming a keen recess encircling the bar. When broken with a smart blow, the surface presents a crystalline appearance, very like cast iron. Put the same bar into a testing machine, and pull it slowly asunder; the area at the fracture will be much reduced, the fibre will be drawn out like a bundle of muscle, and no crystallisation at all will be apparent. If the bar is bent round by hammering until it fractures, the appearance will be very similar. The fibres will be strained, and severed irregularly on the outer radius, and crumpled up and corrugated on the inner radius.

Hence all the tools used in the formative, or moulding processes of the smithy have edges more or less rounding. The fullers — straight, hollow, round faced; and the flatters, &c., all have edges more or less convex. They, therefore squeeze and mould the outlines of the work, but they do not cut it. If we could see the grain of a bar after it had been set down with any of these tools, it would show fibre bent, squeezed, elongated, but with its continuity unaffected; its formation is changed, but its strength is left intact after the employment of such tools.

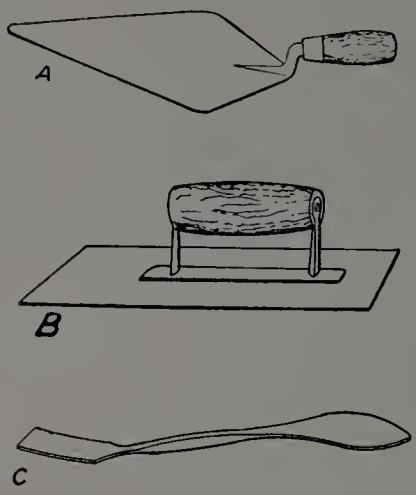


Fig. 251.

The great group of moulding tools is perhaps best represented by the trowel. Its most familiar type is that used by slaters and masons, Fig. 251, A, or by plasterers, B. The trowels of the moulder are like A with variations in outline, as heart, square, dog-leg, &c. The functions of all alike are to smooth surfaces of plastic substances, level or nearly so. The numerous trowel-like tools which are derived from the flat-faced type are employed in the work of finishing moulded forms. The plasterer's tool C is one only in a group. The moulder's tools, of which a selection are shown in Fig. 252, are employed for work in sand.

The moulder uses his trowel for sleeking the joints and the flat faces of moulds, for mending up sand that is broken down, for laying on plumbago, and other functions. In Fig. 252, A is

a flange cleaner, used for mending up and sleeking deep flanges before and after blackening. Vertical faces are smoothed with the flat blade, and the bottom with the return end, with which also loose sand is picked up. The sleekers form a large group. One of these used for deep moulds is shown at B. It has flat ends, and convex faces adjacent. C is a beading tool for flanges, made

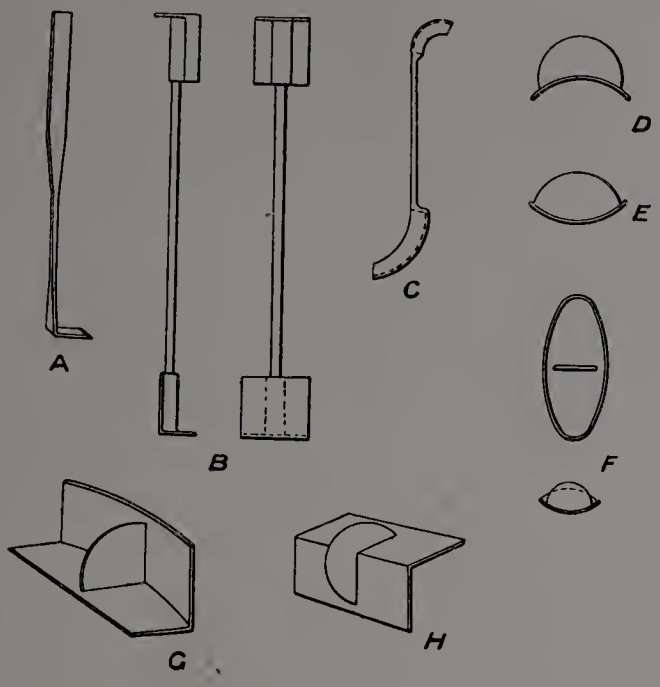


Fig. 252.

in various widths, and radii. D and E are radius tools used in pipe work, and for the general finishing of curves. These also are made in various radii. F is a type of tool, curved in two directions, termed egg, and button sleekers, for smoothing hemispherical forms. Internal and external angles are smoothed with tools like G and H. Both faces may be straight longitudinally as in H, or one straight, and one curved like G.

CHAPTER XVI.

Miscellaneous Tools, and Tool Handles.

Spanners—Wrenches—Ratchet Braces—Woodworkers' Braces—Tap Wrenches—Pincers—Pliers—Tongs—Tool Handles—Forms used for Thrusting—for the Mallet—for Turning—for Planes—for Swinging—Summary.

IN this chapter we discuss as briefly as possible a considerable number of tools which have no particular relationship to each other, or to the great groups which have been already considered.

Spanners, and wrenches are terms often used loosely to distinguish two different tools. In strictness, however, a spanner is an instrument with solid, or fixed jaws, while the wrench with movable jaws, is hence often termed a shifting spanner. Spanners are single, or double ended, wrenches have but one end; the variations in the designs of spanners are not numerous, those of wrenches are.

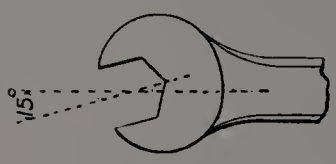


Fig. 253.

The spanners are straightforward, or have their jaws set at an angle with the shank. The object of the latter is to permit the instrument to turn a nut with the least amount of movement, a property which becomes very valuable when working in confined spaces. The most suitable angle for this is 15° (Fig. 253). The explanation is this: A straight spanner will turn a square nut in an angle of 90°, or a hexagon one in 60°. If a spanner has an angle of 15°, it will turn a hexagon nut in a space of 30°. The sizes of spanners are given in the diameters of the bolts they are suitable for. Thus a 1 in. spanner means one for turning the nut of an inch bolt, and the jaws would

Fig. 254.

measure $1\frac{3}{4}$ in the opening. The length of shank is from eight to nine times this width.

A box spanner (Fig. 254) is used when a nut lies down in a circular recess, so that a common spanner cannot be used. The box spanner is turned by a lever or podger inserted in the hole *a*.

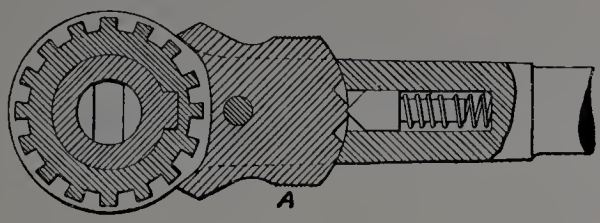


Fig. 255.

The wrench, or shifting spanner occurs in numerous designs. The best are those with double bars to hold the fast jaw parallel. In some wrenches the adjustment is effected by turning a milled nut, in others, by turning the handle. In one form the nut is enclosed within the jaw. Wrenches are not suitable for the heavy general work of shops, but are employed chiefly on repair jobs out of doors, so lessening the weight of tools carried, one wrench serving for many different sizes of nuts.

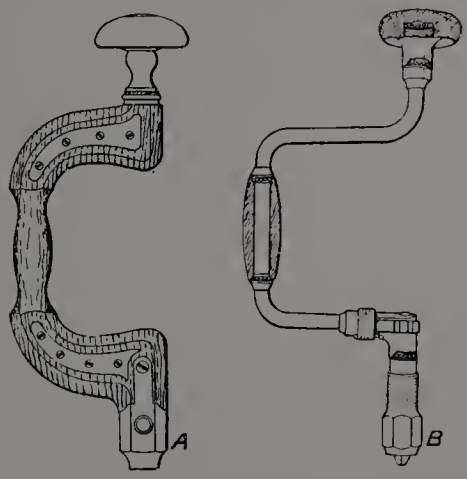


Fig. 256.

Among other lever-like tools are the ratchet braces used for operating drills by hand. The reaction of the pressure on the drill is taken by a "John Bull," which is a pillar and bar rigged up in any convenient position. The feed is imparted by a screw, turned with a tommy rod, while the rotation of the drill and its socket is performed by the dog and ratchet mechanism, turning generally to the right. The objection to the ordinary ratchet is that the drills can only be turned in one direction. To obviate this some types are made as in Fig. 255, double-acting, with a rocking pawl A, which can be thrown over to work either to right

or left, and kept up by the spring plunger, which slips into either of the conical recesses shown. When in the centre one, the ratchet is inoperative.

Fig. 256 shows the braces or stocks used for driving the smaller wood-boring tools, as centre-bits, shell, and spoon bits, &c. The first, A, is the older form, very pretty, but lacking in range of utility, and rather hard to work. B is one of the numerous improved forms, fitted with a double-acting ratchet, for working in confined situations, and being provided with ball bearings in the head, the handle, and the nose.

Another group of lever tools is the tap wrenches, three forms of which are shown in Fig. 257. The first, A, has but a limited

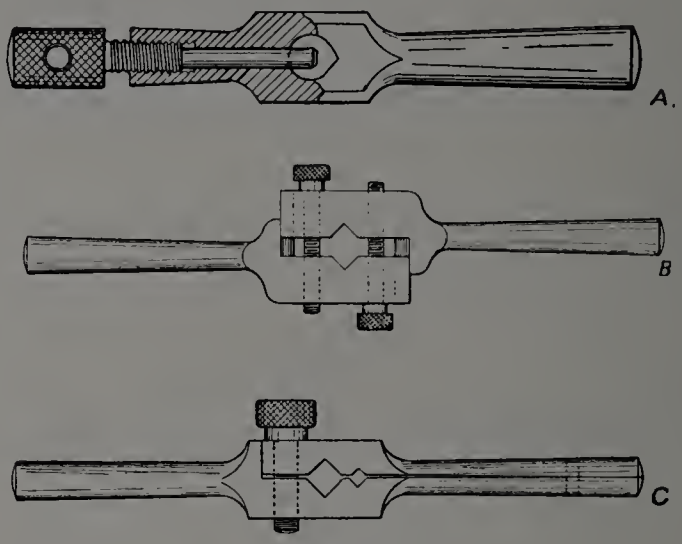


Fig. 257.

range of capacity, the neck of the tap being pinched between the vee and the screwed pin. Other tools, as reamers and broaches, can be held in this form. In B, the jaws and handles are in duplicate, fitting with vees, and the screws permit of a wide range in the grip of the vees. In C an elastic movement is provided, and though it is not much in amount, there are two holes available. Wrenches such as these are better than the common solid hole types, which become slack, and pull the tap necks out of shape quickly.

Another very large group of tools that act by leverage is represented in Fig. 258, A being the common pincers, B the gas pliers. The first is used for drawing nails, the second for tighten-

ing and loosening the joints of screwed pipes. In each case the power exercised is that due to the length of the handles.

Pincers and pliers are often bad in the jaws, either becoming indented when too soft, or breaking away when the steel facing is hard, and imperfectly welded to the iron jaws. When purchasing these new, they should be tried on a tough nail or two at the beginning, and returned if they fail to stand the test. Some pincers are made too convex on the face, and this means a loss of leverage, hence pincers with a flat face are to be preferred.

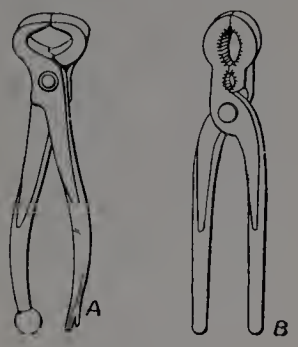


Fig. 258.

Allied to these tools are the various pliers, flat, and round nosed, in which the leverage takes place round the longitudinal axis. These are used for bending wire, and strips of sheet metal. In many, a chisel tool is embodied for cutting off wire,—the cutting pliers, or nippers. Pipe wrenches are modified pipe or gas tongs, being mostly used for larger pipes than the tongs are. Another group includes the tongs used by smiths and boiler

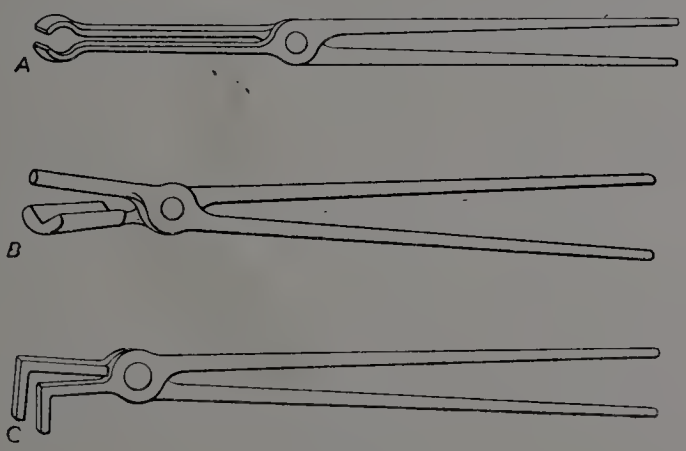


Fig. 259.

makers, three typical forms of which are shown in Fig. 259. The handles are long for manipulating forgings, while the jaws differ in many ways. They are concave in the direction of the axis, or transversely, A. Both jaws are flat, or round, equal, or unequal in dimensions. One is round, and other vee'd, B, for gripping angles. They are straightforward, or turned-down, as in the hoop tongs C,

or one jaw is turned up on both sides to confine work sideways, as in the box tongs.

Cramps embrace all squeezing and gripping tools, from the long bar cramps of the carpenter and joiner, to the small finger cramps used in light bench work. The largest ones will take in as much as 7 ft., which may be increased by the insertion of a temporary lengthening bar. The bar A, Fig. 260, is of rectangular section, made in wrought iron or steel, and is pierced with a number of small holes, pitched at 2 or 3 in. centres. These

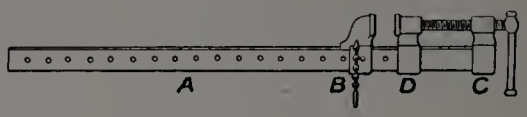


Fig. 260.

holes are for the insertion of a pin, attached loosely to the sliding head B of the cramp, and serve to fix it in any position within the range of the holes, the pin passing either through holes in the head, or simply through the bar behind the head. In one type of cramp, a row of serrations along the top edge of the bar furnishes the means of stopping the head, and the bar is not weakened by being pierced with holes, though this, as a source of weakness, has been exaggerated, since the holes are in the neutral axis. At one end of the bar is a fixed head C, which carries a square-threaded screw, the range of travel of which is about twice that of the centres of the pin holes in the bar. This screw serves to push up another sliding head D, which clamps the work. A block of wood may be interposed between the work and clamp faces to prevent injury to the work surfaces. These cramps range from 3 to 7 ft. in length. Smaller and lighter ones, called sash cramps, are made in sizes below 3 ft.

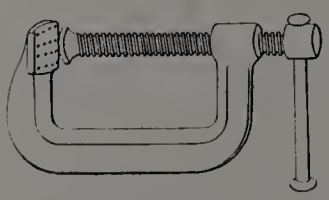


Fig. 261.

Steel G cramps (Fig. 261) are largely employed by cabinet-makers and carpenters, and in stiffer proportions, by engineers. Smaller steel, and malleable iron cramps are very much used, and many of these for metal work have ball heads, which accommodate themselves to out-of-square faces, instead of putting a great strain on the screw sideways. Wooden cramps are very handy where stuff of considerable width has to be gripped. They are usually

cut in beech, the screws being formed with a box and tap. Many workmen construct these themselves, a box and tap costing only a few shillings. Jaws will range from 6 to 14 in. in length.

Screwdrivers (Fig. 262) or turnscrews differ from one another in length chiefly. The longer they are, the more power can be exercised upon them; that is certain, though it is not easily explained, since it does not appear to be due to leverage. All screwdriver handles are broad at the upper end, and more or less ball-like in form to permit of using them as levers. The principal difference in the blades is that between flat and round. The latter are much to be preferred because they will pass down into holes into which the heads of screws often have to be sunk.

Fig. 262.

Of recent years many useful screwdrivers have been developed having a ratchet mechanism embodied, so that the hand grips the handle firmly all the time, and the tiring, and time-wasting shifting of the hand at each turn, to get a fresh hold, is done away with. Engineers use screwdrivers also which differ from the ordinary ones, in having a tee or cross handle, to give plenty of power, for tightening up large screws.

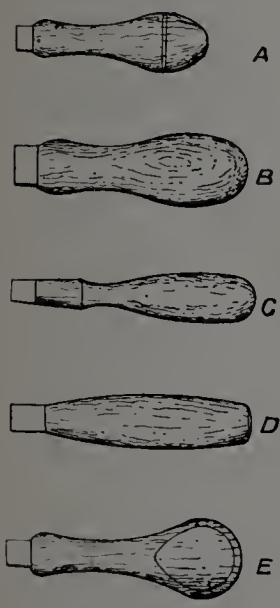


Fig. 263.

The subject of tool handles is one of much importance, though little notice is ever taken of it except by the men who have to use them. A few typical groups are here shown. The forms of handles vary with their functions, being used for thrusting straight forward, or perpendicularly by the hand, or to be struck by the mallet, or to be swung (see Chapter II., p. 30). Obviously the handle is a cardinal part of its tool, co-related to the nature of the work which it has to perform. There is therefore as much variety in one as in the other. When a tool is actuated by pressure, the shape of the handle must be such as to offer resistance to that pressure, without tiring the hand greatly.

Fig. 263 shows a group of handles which are mostly used by simple thrust from the palm of the hand, or ball of the thumb.

A is a bradawl handle, B that of a file, C, and D, for carvers' chisels, and gouges. In each of these, thrust predominates, though occasionally a large bradawl is struck with a mallet, and carvers' tools frequently so, or by the ball of the hand used as a light mallet. E, the screwdriver handle, is both thrust, and turned, hence the reason for the broad end of the handle. A and B are more globular in form at the end than C and D, because the ball of the hand is always pressing against the end, and a small convexity, as in C, would rapidly tire, and make the hand sore. Hence a bradawl handle always has a big ball-shaped end, like a file handle, in order not to tire the palm of the hand, and the ball of the thumb by constant use; a chisel handle should, for the same reason, be well rounded where the thrust of the hand takes place in horizontal cutting (see the group in Fig. 264). The same well-rounded globular formation next the tang affords a good resistance to the pressure of the hand in vertical cutting. The shape of the intermediate portion is of little moment, hence we see it parallel, or sweeped, or faceted, B, C, D, in the kits of different men, in Fig. 264 which represents typical handles for chisels, and gouges, paring and firmer.

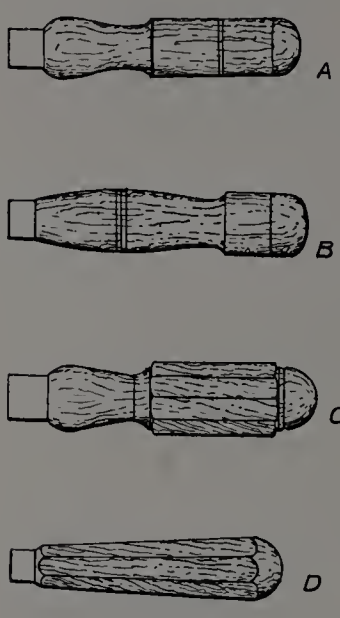


Fig. 264.

In paring and firmer chisels the principal thing required is a handle which can be grasped firmly, without liability of slipping through the hand. Hence the swelled portion, turned with this view, should take the form of A or B, rather than that of C, and the shape of the upper portion is of less importance, being only grasped when paring in a horizontal direction. These remarks apply alike to firmer and paring tools, though in vertical paring with a long chisel or gouge, it is usual to grasp the tool itself, instead of the handle, as being closer to, and affording more control over the cutting edge. D is an old form for firmer chisels, little used now.

The handles of the draw-knife are well bellied to receive the pull of the hands.

In the mortise, and socket chisels the shape is of no account from this point of view, and so we have slightly tapered, or bellied handles (see Fig. 265).

In mortise and socket chisels we have stout handles, too large for paring purposes, but straight, and well rounded at the end, to withstand the bruising and burring action of the mallet.

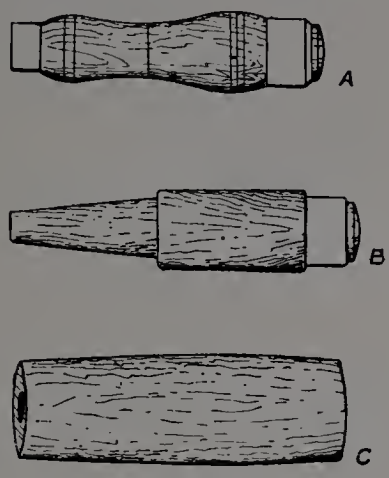


Fig. 265.

In some cases handles are fitted with ferrules at each end, the usual one next the tang to prevent the latter from splitting the wood, that at the opposite end to prevent the mallet from splitting it (Fig. 265, A, B). This ferrule is, however, awkwardly placed when using a chisel by hand alone, and it should therefore be adopted in the mortise tools only. Though the handles of most chisels are of circular section, mortise chisels are a frequent exception, the tanged kind being elliptical in cross section, C, so that they do not turn about in the hand. The handles of axes and adzes are elliptical for the same reason, to prevent turning in the grip. In all these matters nothing comes by chance, but there is a practical reason for every difference in detail.

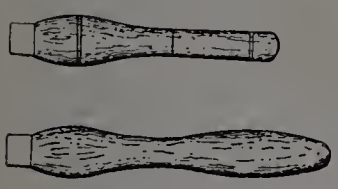


Fig. 266.

The handles of turning tools (Fig. 266), are levers mainly, by which the tools are controlled. Long handles are necessary to prevent risk of the catching of the tool points. The illustration shows two alternative forms.

Handles of planes and saws are shown in Fig. 267, A being used for jack planes mostly, B for trying planes, C for hand saws, and slightly modified for tenon, and dovetail saws. Fig. 268 shows handles which have to be swung in a radius, A being the adze, B the axe, and C the hammer. Variations occur in these, especially in the two last. Certain proportions are insisted on by some men in axe handles, particularly those of the American form. Hammer handles vary in length, from the bench hammers

of from 12 in. to 18 in., to the sledges of 3 to 4 ft. This group of handles is elliptical in cross section, to prevent turning in the hands.

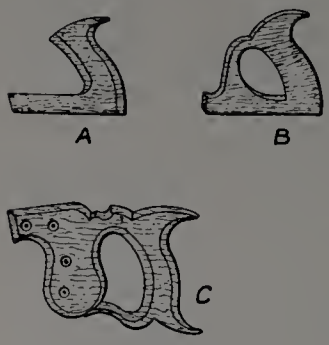


Fig. 267.

Some men, both workmen and amateurs, take great pride in handles of their chisels and gouges, as for instance, having all the tools in one set handled in one kind of wood, and again in choosing expensive and fancy woods, as boxwood, rosewood, ebony, lignum vitæ, lancewood, snakewood, greenheart, logwood, &c. Snakewood looks very pretty, greenheart and lignum vitæ are hard to bore, and brittle; rosewood is also brittle, but handsome when polished, logwood is open in the grain; but the best of all is boxwood, being hard and tough, and the only one of the whole which will stand the mallet for any length of time. For the mortise chisels, however, nothing beats beech, or ash.

Fig. 268.

Many tools have no handles, being struck directly with mallets or sledges, or gripped in the holders of machines, or in special holders, afterwards set in machines, or, as in the moulding planes, the body or stock being grasped. In some cases, the tools and handles are in one solid mass, the handle being formed by an extension of the shank of the tool. In others the handle is developed into a more elaborate affair, as in the bow and hack saws, where a strain is imparted to the saws by a cord, or a screw.

Some tools, like the cross-cut saws, and the pit saws, have a handle at each end in the form of a cross, so that two men can operate them. Augers have cross handles to afford ample leverage. The handles of tools, like the tools themselves, are the result of a process of evolution from periods thousands of years distant.

SECTION V.

HARDENING, TEMPERING, GRINDING, AND SHARPENING.

CHAPTER XVII.

Hardening and Tempering.

Distinction between Hardening and Tempering—Method of Heating—Precautions—Methods of Hardening—Quenching—Drawing Temper—Annealing—Mechanical Processes.

HARDENING and tempering are two distinct processes. The first signifies the making a tool intensely hard, the second produces a certain degree of hardness, which varies widely in the case of tools for different purposes. Usually, though not invariably, hardening is a stage towards tempering, because it is generally easier to harden first, and then "let down," for temper, than it is to raise a tool to the exact heat required for tempering. The latter method is, however, used largely when mechanical aids are employed for determining the heat necessary for tempering. At the forge fire, temperature is estimated by colour, the principal stages of which in the ascending scale are represented by straw, and gold in various shades, chocolate, or brown, purple, violet, and blue. The first is suitable for tools of great hardness, the last for springs, or tools which should be springy. Researches into the chemical characteristics of carbon steel have not as yet been of much practical use to the smith. He knows that various grades of carbon steel require different treatment, and that there is an unbroken range of temperature between blue and yellow available for articles of different kinds. Every new stock of steel which comes into a shop has to be subjected to its own special treatment. If a new stock, though of the same brand, containing the same amount of carbon, and supplied by the same

firm, were treated exactly like previous stocks, disappointment as regards hardening and tempering would almost certainly result. But broadly, every brand of steel is suitable for special tools, and in a general way requires the same kind of treatment.

Steel tools are heated at the forge, in air furnaces, in tubes and boxes, on hot plates or bars, in metallic baths, and in gas flames. The differences between heating articles simply in the open fire, and in closed furnaces, is that the colour test is adopted in the first, and the thermal test in the second. Tools such as cold chisels, and those used for planing, shaping, and slotting, are commonly heated in the open forge fire, or in a tube placed in it, coal or coke being the fuel used. But milling cutters, drills, taps, or reamers should be heated in a charcoal fire, or in a tube, furnace, or bath, in order to protect the tools from contact with sulphurous fuels, and uneven temperatures. Blast should not be used when heating steel at the forge, because the cold air is liable to warp the work; a hollow fire should be prepared first, and the blast shut off before the tools are introduced. But blast may be used when the work is enclosed in a tube. A tool should be kept in constant movement in the fire, to ensure equal heating throughout. Soaking should not be prolonged more than is necessary to ensure uniform temperature. Steel must never be overheated, since it causes burning, brittleness, and coarseness of grain. Hence the invariable rule, always to harden or temper at the lowest heat which a given grade of steel will take. A sign of overheating is that at which scale forms and falls off. A welding heat should never be reached in steel tools, the case of the high speed steels alone excepted. Should the end of a tool become overheated, the best plan is to knock it off, and reforge. A cherry red in a dull light, say in the shadow of the forge, represents the highest temperature to which carbon tool steel should be subjected. Scale must always be removed previous to tempering.

When steel is heated in furnaces, a sample piece is first dealt with before a quantity is subjected to treatment. The advantages of gas over solid fuel are the exact adjustment of temperature by means of valves, its uniformity throughout the furnace, the non-oxidation of the steel, the fact that large numbers of pieces are under perfect control, and to a large extent the elimination of the personal skill of the smith. Furnaces are of especial value in heating thick work, a difficult thing to do in a forge fire. As

dimensions increase, the difficulty of tempering increases. Hence the trouble which arises in the tempering of large milling cutters, which, when of over 6 or 7 inches diameter, are better made with inserted teeth than out of the solid. A similar difficulty occurs in the hardening of long taps and reamers which warp in quenching, and the teeth of which often become burnt before the body is saturated throughout.

Tempering baths of molten metal are composed of lead and tin in varying proportions, different compositions of which provide a considerable range of temperatures suitable for the smaller tools.

Tools are hardened in rain water, rather than in well water, the reason being that it contains less lime than the latter. It is a curious fact that water which has been in use for a long time is better than that which is fresh, hence the smith's bosh is seldom emptied, but only replenished. For general purposes tepid water is preferable to cold, and the water soon becomes warm by the repeated dipping of work into it. Rock salt is frequently added, with other ingredients, as potash and borax, which are hardening agents. Other hardening agents are sal ammoniac, alum, corrosive sublimate, ammonia, parings of horses' hoofs, yellow prussiate of potash, yellow soap, oil, lard, wax, suet, tallow, beeswax, spermaceti oil, pitch, black rosin. Tools can be made harder in mercury than in any other liquid, ice or ice-cold water comes next, or a lump of lead, into which the points of small drills are sometimes thrust to harden them. But for by far the larger number of tools, water, with or without some of the medicaments just mentioned, is employed.

There are right and wrong ways of quenching tools. The following is the general method of letting down, when hardening and tempering are done in one operation, or rather in two successive operations at one heat. The tool is brought to a red heat two or three inches from the cutting edge, then plunged vertically into water for an instant or two, so hardening the surface. It is then withdrawn, a portion is rubbed bright with a bit of broken grindstone or emery wheel, and the change of colour, due to the heat in the centre and shank spreading to the surface, watched, until the colour necessary for the particular temper desired appears. Then it is dipped in the water, and moved about therein until cold. The smaller tools are frequently raised directly to the

temperature required by being laid on a bar, one end of which is red hot, until the tempering colour appears. When a heated tool is plunged into a water bosh it should not be allowed to remain still, but be moved about vertically. The reason is that the water in immediate contact with the hot steel becomes converted into the spheroidal state, each globule being surrounded by a film of steam, which delays the hardening process. Movement of the work brings it into contact with cooler water. This explains why mercury, which does not volatilise at the temperature for hardening steel, is the most perfect hardening agent.

The high speed steels are not quenched in water, but in air, either in still air, or in a blast. They are not tempered, but hardened, being heated until the tips of the tools begin to melt. These, however, are not carbon steels, but owe their hardness to tungsten, molybdenum, &c.

The question of hardening and tempering is a wide subject, which can only be touched on lightly in a volume of this character. A few remarks on different tools will therefore conclude this section. Taps and reamers are not let down in the same way that chisels are. They are hardened first, and then reheated for temper. It is usual to cover the teeth to lessen risk of cracking—oil, flour paste, or soap and oil, or yeast are used for this purpose. They are generally enclosed in a tube in the fire, the lower end being plugged up. Or if produced in quantity, they are heated in a box of charcoal powder, placed in a furnace. The water for quenching should have a temperature of about 80°. The colour should be a light straw, and the square necks a blue. Such tools should always be plunged vertically, to lessen risk of warping. Dies are heated to a cherry red, and hardened in raw linseed oil. They are reheated to a medium straw, and quenched. Hobs and milling cutters are frequently heated in a box in charcoal powder, hardened, and then tempered in water at 80°, to which soft soap is often added. Punches are tempered at a brown, or a dark blue. Thin pieces of steel, such as knife blades, are frequently tempered between stout plates of iron, to prevent risk of warping.

When hardened tools require to be recut, the temper has to be drawn, preparatory to recutting. To draw the temper of tools, place them within a tube made hot in the fire. They may be then allowed to cool slowly in sawdust or wood ashes, or in

powdered charcoal. Another operation which is often performed, is the annealing of steel, preparatory to hardening and tempering. Its object is, to lessen the risk of distortion, and cracking. It is of especial value in such tools as milling cutters, taps, reamers, which are peculiarly liable to go out of truth. It is effected in the same manner as drawing the temper, heating slowly, and cooling down in the above-mentioned substances.

The foregoing remarks refer chiefly to work done by the smith at the forge, but in large manufacturing processes the occupation of the smith is gone, displaced by semi-automatic mechanism. In some cases the articles are carried through the furnace by mechanism, becoming heated during their passage, and discharged automatically into the cooling bath, articles with holes are stuck on pins standing out from an endless chain, that passes into the furnace at one end, and out over the hardening bath at the other. Sometimes small pieces are laid on trays, which rotate horizontally in the furnace, or they are carried through on an iron link belt. In continuous heating furnaces, the hardening bath is maintained at a constant temperature; in some cases, the hot liquid is drawn from the top, run down through pipes, and pumped back when cooled. Or the tank is jacketed with cold water, circulating around it at a suitable rate; in others, ice is employed for keeping the temperature down.

CHAPTER XVIII.

Tool Grinding and Sharpening.

Hand Grinding—Variable Results of—Mechanical Grinding—Due largely to Emery Wheels—Precision of—Natural Grindstones—Lack of Homogeneity—Composition—Hardness and Softness—Glazing—Truing—Double Grindstone — Speeds of Running — Mounting — Water — Comparison between Grindstones and Emery Wheels—Grading—Speeds of—Truing—Forms of Wheels—Wet Grinding—Tool Grinding—Tool Grinders—Examples of, for Hand Grinding—Grinding Woodworkers' Tools by Hand—Plane Irons—Gouges—Sharpening—Wire Edge—Errors in Practice—Gouge Slips—Mechanical Grinding—Examples of Machines for Single-edged Tools—Sharpening Reamers—Milling Cutters, &c.

TOOL grinding is a wide subject in regard to the classes of work done, and the methods by which they are accomplished, and there is a corresponding variation in the grinding machines adapted to, or constructed for the purpose.

In all grinding, a movement of the tool relatively to the wheel is either essential or desirable. It is essential when broad facets are being ground, in order to prevent glazing of the wheel, because moving the work permits the swarf to get away. It is desirable as a means of preservation of the truth of the wheel, a traversing movement of the tool wearing it away equally, instead of cutting it into grooves.

In a large number of shops to-day—as in all until a few years ago—tool grinding is commonly done by hand, without any assistance from mechanical aids. The custom then was, and is still, to bridge the trough just in front of the stone with a piece of square bar, and to use this as a rest upon which to lay the tool during grinding. As the stone becomes worn down, the bar is set along to follow it. The tools for lathe, planer, shaper, slotter, and drilling machine are thus ground without any further aid, being held in, and manipulated by the hands. The ends or faces of the tools are held against the stone, the latter revolving towards the work-

man, so imparting the front rake. The top rake is imparted by laying the tool on its side against one edge of the stone. Whatever angle, and whatever profile is wanted, is produced by giving the requisite inclination to the tool in relation to the stone, and by moving it, or holding it rigidly, according to the shape wanted in plan, whether a straight, or a curved face, &c. In order to maintain something like uniformity of cutting angles, gauges of sheet metal having certain angles filed in them are sometimes kept by the men, both for use with common tools, and with drills. Actually very great variations are found in tools in a shop where this system prevails, even for those doing the same class of work, in nominally the same class of metals.

This system has been abandoned in those shops which have endeavoured to bring themselves into line with modern requirements. There are obvious objections to it, partly by reason of the waste of time which it involves, and partly because it is a loose kind of practice, in which every man does that which seems right in his own eyes, too often without much basis of common-sense in regard to the appreciation of the conditions which underlie the action of cutting tools. In a few cases there might be some advantage in the system, as, when a man by long experience has learned how best to vary the angles and the shapes of the cutting edges of tools, so that they shall operate with the highest efficiency on different grades of metals and alloys. It is well known that men hold different opinions as to the best shapes to give to tools for certain purposes. But the waste and loss, and generally the poor results of the system have condemned it in the best practice, and its place is taken by mechanical systems of grinding involving a series of uniform angles for tools which operate on similar materials, and in some instances, as a matter of convenience, uniform angles for materials which are, in some degree at least, dissimilar in physical characteristics. The system is still retained extensively, being only partially displaced by the later one of greater precision. But in numerous instances the emery wheel has taken the place of the grindstone, and is fitted up with rests of tee or other shapes, in which more care is taken of the design than of old.

It is largely due to the emery wheel that a better shop system has been introduced than that which prevailed before. It was formerly thought that only stones, either natural or artificial,

were suitable for tool grinding, because the tools could be then kept cool by the application of water. But since emery wheels have been rendered insoluble in water, the conditions have become changed. And of late years wheels of corundum, and those of carborundum—a product of the electric furnace—have entered into rivalry with emery. Carborundum is a more durable material. Instead of each man now going to the stone to grind his own tools according to his taste and fancy, they are done in batches in the toolroom to uniform angles, so that all over the shop, tools which have to do the same class of work are ground precisely alike, and the lathe, planer, or shaper is not left standing idle, in consequence of the attendant being always at the stone waiting his turn, or spinning a quiet yarn with a mate. The more precise the work done by the tools, the more need is there of having emery wheels fitted up with suitable rests, or holders, and provision for setting to the exact angles which have been predetermined on as the best. There is then no guess and trial, no setting and checking, but the tool can be put in its rest, or box at once, and started to work. As the emery wheels are run at higher speeds than stones, they are protected with hoods, which in some tool-grinding machines cover the upper part of the wheel only, so that both sides of the latter can be used. The water, too, instead of being dropped or poured over the wheel from above, and gathering centrifugal force with the wheel, with excessive splashing, is directed exactly at the grinding zone, and is confined to that area by means of broad plates of metal.

Natural grindstones are obtained from the millstone grit, a Carboniferous formation. They are largely quarried in Derbyshire, near Rowsley, and Stanton, and at Hardsley, and Wickersley, situated a few miles distant from Sheffield. These are hard and coarse stones, suitable for heavy work. Bilston stones are used for fine cutlers' work, as also are the Sheffield bluestones, found close to the town. But the largest proportion of grindstones used in this country come from the Newcastle district, from the quarries of Messrs Kell & Co., R. Pattison & Son, and R. Robson. They are of a natural siliceous sandstone, which has been quarried for more than a hundred years for the purpose. Stones as large as 8 ft. in diameter, by from 12 in. to 16 in. thick, are supplied by these firms.

The chief trouble in a natural stone is lack of homogeneity,

and the larger the stone, the more difficult is it to secure freedom from the presence of fossils, particles of iron, and seams. The presence of seams, however minute, is fatal to the safety of a stone revolving at a high speed, and it is not always easy to detect these when of slight dimensions. As a stone becomes reduced in diameter, in consequence of wear, the speed has to be increased, and in this way a stone is often more liable to fracture after having been in use for some time than when first hung. In order to diminish the risks of seams or flaws developing, it is the practice to rough-hew the stones when fresh from the quarry, and then lay them aside for a while to dry, and harden, when there is a greater chance of flaws becoming visible.

Other properties besides homogeneity are requisite, as relative hardness or softness, fineness or coarseness of grain, rapidity or otherwise of cutting, the general texture of the particles, whether smooth, or angular and sharp. Hence when ordering a grindstone it is necessary to state the exact purpose for which it is to be used. It is because of unsuitable selection having been made that complaint is frequent of glazing, though this is often due to running at too high a speed. The texture of stones varies widely, ranging from grains of almost microscopic minuteness, to those of about the size of a pea. Such being the case, it is possible to obtain any quality desired for quick or slow cutting, for fine or coarse finish. The best stones show so little grain, or traces of stratification that it is often difficult to detect it.

Silica is the principal element in natural grindstones, amounting to more than 80 per cent. It acts as a cementing material, in common with carbonate of lime, and oxide of iron. On the due proportioning of these elements the texture of a stone largely depends. Silica in excess produces extreme hardness; much carbonate of lime, and iron oxide render stones too soft for grinding purposes. What is termed "grey grit" is that suitable for grinding engineers' tools.

Hardness and softness are relative terms in speaking of grindstones, these qualities depending on degrees of coarseness or fineness, as well as on absolute hardness or softness. A fine grit stone may be softer than a coarse grit one, and yet operate as though harder, because of the slower action of its particles. A hard stone is of little value for engineers' general use, because it acts too slowly, and becomes glazed quickly. In a soft stone the

particles cut rapidly, and are themselves abraded, exposing a fresh layer beneath. The water also penetrates more readily between the particles, and washes away the swarf before it can become embedded in the stone, and so carries off the heat generated in grinding.

When the surface of a stone becomes glazed, it must be turned down, since the gritty particles offer no projecting points for action. A stone that glazes quickly is of no use, because of the cost of keeping it in order, and the waste of time involved in the slowness of its operations. The writer has read of granite bearimgs being sometimes used for water wheels in Sweden, because of the perfect manner in which they glaze, becoming like metallic surfaces. If a stone is too soft, there is the evil of too rapid wear, and cost for renewal. Some soft stones cut rapidly, others are so soft as to be nearly useless.

Grindstones are trued with a pointed bar of iron or steel, or with the end of a piece of gas pipe, or with a special appliance termed a "grindstone truer," of which there are two or three types, and by which the operation is facilitated.

To turn a grindstone with a pointed bar or a tube, it is revolved at a slow speed—not more than eighty or ninety revolutions per minute,—and is run dry. The bar taken is about $\frac{1}{2}$ in. or $\frac{5}{8}$ in. square, and is of iron or steel—it does not matter which, because the bar loses its keen edge instantly, and its effective action depends on the constant and rapid change of position by which fresh facets are applied to the stone. The bar, therefore, is kept in continual motion, being rotated on its own axis—presented at slightly different angles—and traversed across the stone at one and the same time. It is held at a vertical angle, constantly varying. but averaging somewhere about 15° to 20°.

When a stone is newly turned its surface is finished to a slight convexity, because all shop stones tend to wear hollow, by reason of the grinding being done less, at, and near the edges than about the centre. The narrow tools of the machinist, and the gouges of the patternmakers, and joiners soon wear concavities. The edges of the stone should also be trued for an inch or two downwards, because it is often necessary to use these edges in grinding.

Muir's double grindstone is designed with a view to obviate the necessity of frequent retruing. Two stones are run edge to edge, with adjustable centres, and men can work at each.

The stones keep one another true by the slight contact which takes place.

It is not easy to say at what speed grindstones should be run. We perhaps err on the side of extreme slowness; the Americans go to the other extreme, running their stones at rates perilously near to the bursting point. We make a great difference in the speeds of grindstones, and of emery wheels; they think no such differences should exist. Since time is money, they run the stones to their utmost limit. In some American shops the grinders have a very matter-of-fact way of ascertaining the highest speed at which it is safe to run them. They test the stones at a rate rather higher than the highest which experience tells them is desirable, and then if they stand it they use them at a speed a trifle below. Stones there are commonly run at peripheral rates of between 4,000 and 5,000 ft. per minute.

The peripheral speed of a stone in English machine shops used for grinding tools probably ranges only from about 800 to 1,200 ft. per minute, or in the case of a stone of 3 to 4 ft. diameter from 90 to 100 revolutions per minute; being therefore the same speed as slow main-line shafting, it is run by pulleys of about equal diameter on shaft and stone. It is not necessarily supplied with fast and loose pulleys, because it is kept running all the while for constant service, which is better also than allowing it to stand in the water. As stones wear down, the speed, of course, should be increased. But the usual practice in shops is not to alter the speed, but to replace the stone with a new one before it wears very small—that is, when a 3 ft. stone wears down to, say, 2 ft., it is taken out, and the 2 ft. stone finds a place elsewhere.

There are two methods of mounting grindstones. One way is to have a square hole in the centre of the stone, into which a square axle, measuring across the flat from $\frac{3}{8}$ to $\frac{1}{2}$ in. less than the hole, and having the ends turned down to form suitable journals, is fitted tightly with wedges of hard wood. The operation is termed "hanging the stone," probably from the fact that during the fitting of the wedges, the adjustments are made by turning the stone from time to time until that degree of correction effected by the wedges is reached at which the stone runs true. Once the wedges are adjusted and driven tightly they seldom work loose, because the water keeps them in a swollen condition. This is the old millwright's way, and for grindstones it is as good as the alter-

native fashion of having a round hole, round axle, and side clamping plates.

Water is generally fed on the grindstone from a can fixed over it. The tap is turned to allow the water to drip slowly without causing it to be unnecessarily thrown off, and splashed. The custom of partly filling the trough with water, and allowing the stone to run in it causes much mess; while keeping the water below the stone, and splashing up small quantities with a flat piece of wood, is a clumsy and disagreeable practice.

In the commonest method of watering a stone by letting the water run down from the spout of a drip-can, keeping the tool to be ground in the vicinity of the dropping water, there is no distribution of the water over the breadth of the stone. A frequent practice, therefore, is to let the water fall on to a piece of cloth suspended from the drip-can stand, and lying across the stone a few inches higher than the area where the grinding is done. The water is then distributed over the whole breadth of the stone evenly, and without splashing occurring.

The grindstone consists of a multitude of sharp cutting points held together with a cementing materal. As the particles become abraded, the cementing material is also softened, or dissolved, and removed. The water used dissolves the cement. Hence the reason why stones which stand in water become softened in that part which is in the water. It was by an application of this principle that Poole's wheels for calender rollers were made. They were of emery, cemented with substances soluble in soda water. The wheels being kept wet with an alkaline solution, the cementing material on the surface became dissolved, and fresh grinding surfaces were continually presented to the work.

Probably the capacity of the common grindstone has never been developed as it might have been in engineers' shops. That of the emery wheel has, and therefore comparisons between the two have not been made under the same conditions. To-day the grindstone is considered an antiquated, and is often an ill-used piece of mechanism. Sometimes selected without regard to its requirements, it is too soft, or too hard for its purpose; or it is not homogeneous, and consequently wears unequally. It is allowed to stand partly immersed in water, so softening it locally. It is used so badly that it loses its circular form, and becomes cut into grooves so that accurate work is impossible. Nobody is re-

sponsible for it, and only when it becomes scored very badly, a shop labourer turns it up. It is nearly always run at too slow a speed—at a mere crawling pace. Such are the conditions under which it exists in many shops to-day.

With emery wheels different conditions exist. They are generally homogeneous, and their grades are regulated with more or less care, according to the special work they have to do. They are fitted up with suitable bearings, their speeds regulated by the manufacturers, and the general conditions under which they must be employed are insisted on. Generally, they are used by the regular grinders only, part of whose business is to keep the wheels true, and in good general order. If the same care and attention had been given to the grindstones as to the emery wheels, it is probable they would not have been displaced to the extent to which they have been.

Emery wheels are graded by coarseness or fineness, and by softness or hardness. The first are known by numbers, the second by letters. Between the extreme range in each lie all shades of difference, and in this fine graduation lies one of the chief advantages of the emery wheels over the grindstones. Besides these, other governing conditions come in to supplement, and influence the selection of wheels, such as the width of wheel and width of work, the nature of the material being ground, and the speed—matters the settlement of which being to some extent mutually dependent, require considerable experience in the work of grinding.

As very general rules only, subject to the usual exceptions, soft wheels cause less change of temperature in the work, and glaze less than hard ones. Coarse, soft wheels can be run at higher speeds than fine, hard ones. Having a wide surface of the work and wheel in contact, the wheel should be softer than for narrower surfaces. But it is well to use a wheel of the fullest width practicable. The use of water is serviceable in preventing changes of temperature, which would draw the temper in cutting tools. The best wheels are those which contain least cementing material and most emery, or which contain a cementing material having cutting qualities similar to the emery.

There is much variation in the speeds of emery wheels, ranging from about 4,500 to 6,000 ft. per minute peripheral speed. About 5,500 ft. seems to be the most suitable from the point of view of practical efficiency. The faster a wheel revolves, the quicker will

it cut, but the more rapidly, too, will it become worn out. Exact experiment has borne out common knowledge that high speeds are the most economical.

It is even more necessary to true an emery wheel when it has worn slightly out of truth, than a grindstone, because of the difference in speed, the rapidly revolving emery wheel when out of balance being more liable to fly asunder than the stone. Emery wheel dressers are supplied of the circular type, held in the slide rest similarly to a knurling tool for milling the edges of the heads of binding and micrometer screws, &c. The edges of the circular cutters are pointed like saw teeth, and they reduce the emery by hacking out the grains. The wheel must be revolved slowly, at a peripheral speed of 80 to 100 ft. a minute only, and the cutting must be light. The dressing must be done from the edges towards the centre to prevent risk of the edges breaking away. In turning down emery wheels to sectional forms the best plan is to use a black diamond held in a slide rest, taking light cuts, as the diamond is very brittle. These are rather costly, and therefore plain and heavy wheels that have not to be turned to sectional forms are often turned by cross-hatching them first, similarly to grindstones, and then turning the chipped surface with the jagged edge of a piece of boiler plate that has been punched or shorn to outline. Or the wheel dressers just mentioned are employed; and this is much the better way.

Emery wheels are either discs, rings, or cylinders, and they are plain, or of numerous sectional shapes to suit special work. Discs are the most common, being employed for general purposes of all kinds. Rings are used to save the waste of the central part of a solid wheel, which, when the wheel is worn down, becomes too small to be of any further service. With the cylindrical wheel, work is ground on the face, and no alteration of speed due to wear is necessary, because there is no reduction in diameter.

The practice of wet grinding, which is a secondary development in the use of emery wheels, has attained an importance equal to that of the original dry grinding. Tools are ground thus, and also work, in which a rise of temperature would be objectionable as affecting dimensions. The designs of wet grinders therefore are very numerous, and have attained a high degree of excellence.

Water-trough tool grinders, it may be mentioned, should be fitted with a door near the bottom to permit of clearing out. In some

machines of the floor stand type, in which the base serves as a water tank, fitted with centrifugal pump and adjustable water pipe, the hood is made with an opening, and a planed top. Consequently, flat surfaces can be ground on this, besides the tool grinding that is done at the front. When flat grinding is not being performed, the opening is closed with a cover.

In one good and common tool grinder a trough of semicircular outline in front serves as a water pan, this outline permitting the workman to get round easily to either side of the wheel. Adjustable guards prevent the spray from flying about over the man and the surrounding objects. The tool rests are moved back as the wheels wear down, and the use of gun-metal bolts prevents rusting up. The water supply is adjusted exactly as wanted by means of a hand wheel, and once adjusted, the supply remains constant. The wheels are kept true by turning a hand wheel, without removing any parts. Tool grinders of this kind are made either single or duplicated on one stand.

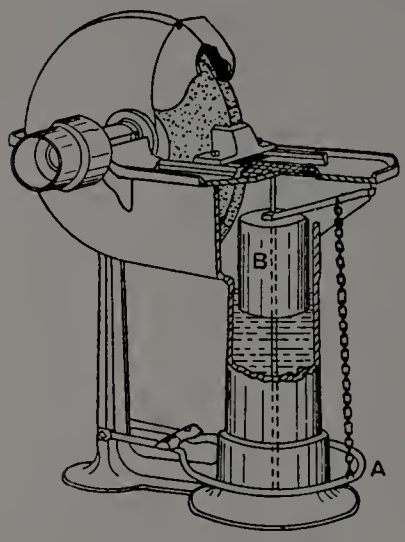


Fig. 269.

In the Barnes grinder (Fig. 269) the supply of water is regulated by a treadle. The front portion of the grinder is a hollow standard containing the water, in which there is a float B nearly filling the column. The workman, when about to start grinding, simply steps on the treadle, which pulls the float down into the water, causing the latter to rise round the wheel. Releasing the foot, the float rises and the water falls back.

When the float is pressed down, the water passes slowly through a small hole in a partition that separates the pillar from the trough, and is carried up round the wheel to the upper front part, where it enters a chamber opening on the wheel just above the tool to be ground. This permits of a regular and moderate flow of water just where it is wanted without unduly flooding the wheel. In the Gould & Eberhardt tool grinder the water is supplied to the wheel by a pump at the side of the machine.

Small bench emery wheels are fitted for wet grinding of tools.

The peripheral speed is less than half that used for dry grinding for general purposes, being at the rate of about 1,800 ft. per minute. Such machines can be located about a shop where the men do their own grinding. The wheel is covered by a hood except where grinding is being done.

The tool grinder of the Leland & Faulconer Company (Fig. 270) includes several devices of an interesting and practical character. The tool that is being ground is laid upon a rest which

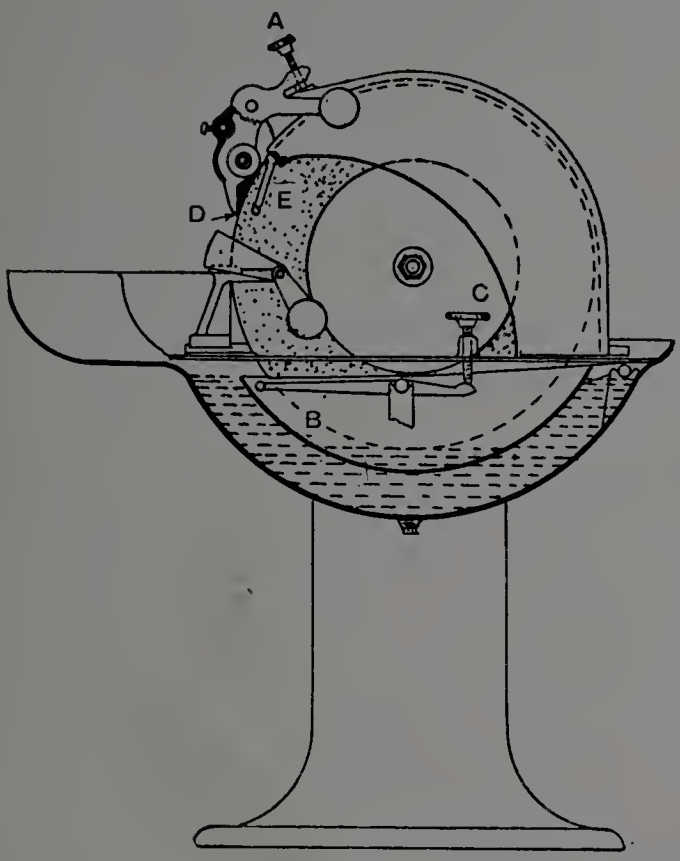


Fig. 270.

is protected by a counterbalanced guard from the splashing of water, the guard rising up over the face of the wheel when the latter is not in use. The truth of the wheel is maintained with frequent dressing by means of a truer that is always kept close to the wheel at the front. This is a threaded roll of steel, which is pressed into light contact with the wheel for a few minutes each day by turning the knob A above. The supply of water is regulated by means of a hinged pan B within the main trough, the

latter containing a constant supply of water, the former a variable volume which is graduated at the will of the attendant by means of a small hand-wheel C that, moving a lever, depresses the front end of the pan. The amount of depression regulates the entering volume of water. The pan is balanced. The water is carried round the wheel and distributed through the passage D in the face and through tubes E at the sides.

In a tool grinder by the Whitney Manufacturing Company, of Hartford, the supply of water is regulated by means of a handle at the side, slipping into a number of notches in a quadrant, in each

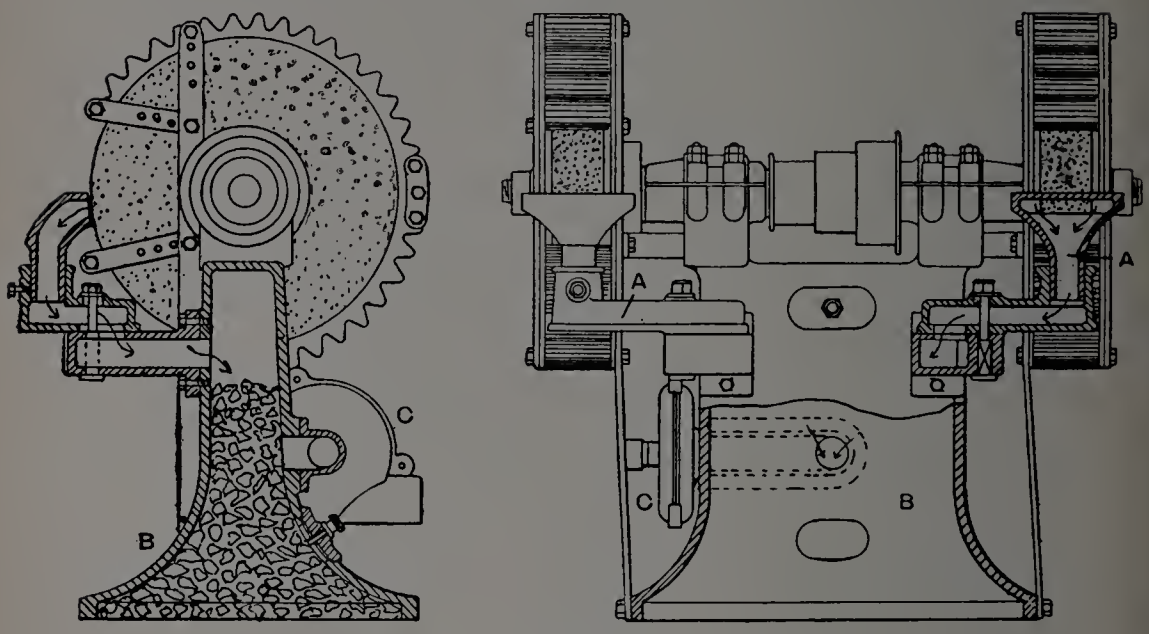


Fig. 271.

of which notches a different volume is obtained from the tank beneath.

A grinder by Messrs Mayer & Schmidt, of Offenbach a/Main, adapted for dry or wet grinding, is illustrated in Fig. 271. It is fitted with an exhaust fan to remove dust, and the details of the arrangement are novel and interesting, because the means which are provided for the removal of the dust are contained in the ordinary framework of the machine, doing away with the necessity of having special dust collectors. The rests themselves, A, A, are made hollow, and brought into communication with the hollow pedestal B, which is completely enclosed, and more than half filled with a solid filtering material, preferably coke. The ventilating exhaust

fan c is in communication with the hollow space, and is driven from a belt on the collar of the wheel flange. The dust is therefore drawn directly from the spot where it is produced, through the hollow rest into the pedestal, where it is caught by the coke and falls down into it, the large area of the space being favourable to its quiet deposition. The deposit can be cleaned out at intervals. It is pointed out as one of the minor good features of this arrangement that the dust of brass and copper can be recovered for remelting. For wet grinding, a centrifugal pump is fitted.

The remarks immediately succeeding relate to the actual mechanical work of grinding, and sharpening wood-working tools.

Nothing can compensate for the absence of a good cutting edge on a tool. Mere muscular force will not make a bad instrument cut well, files and glass-paper are of little use where accurate results are required, and quite out of place in the best work of all. The keenest, finest edges, and lines should be left as the tool makes them. Hence frequent recourse to the grindstone and hone is necessary, and not less essential is the knowledge how to employ these.

The grinding of a cutting tool is not an easy task, especially one having wide edges, such as those of broad chisels, and plane irons. As the angles of tool edges for various materials are constant, various mechanical contrivances have been devised for holding them at set angles while being ground, in order to supplement the efforts of unskilful hands. There is little objection to these, but they may be regarded in the same light as a swimmer regards corks, as being more of the nature of an encumbrance than otherwise. By long practice the workman learns to *feel* the bedding of the tool upon the stone, and knows at once when the facet has moved away from contact. Moreover, a mechanical aid means, that whether the stone be true or not, the tool must remain stiffly in one position, to partake of its misshapen outline, where such exists, while by unassisted hand grinding, accurate results may be obtained even from a badly shaped stone. The use of fixings is therefore generally more troublesome than grinding by hand alone.

In grinding a plane iron, the stone should revolve towards the iron, not away from it. It is comparatively easy to hold the iron firmly while the stone is thrusting it towards the worker, but difficult to hold it steadily under the opposite conditions. The top

iron is usually screwed in its place on the cutting iron, but a little further back. It serves as a guide to grinding square across.

When grinding firmer, or outside gouges, and round-nosed tools, the curve of the face involves a frequent change of position of the tool, which is, in the former, effected by a rotary motion of the wrist, in the latter by a horizontal sweep of the hand. In grinding the gouge, the tool is held parallel with the edges of the stone, and rotated on its longitudinal axis, and, owing to its hollow form, the angle which the facet forms with the cutting face becomes constant all round. But in grinding the round nose, the tool must be rotated round the point, or cutting edge, else the angle of the facet would not be constant.

Paring gouges are troublesome to grind, unless a special stone is available. In many shops they have to be reduced on the edges of the large grindstone—easily done when dealing with large flat

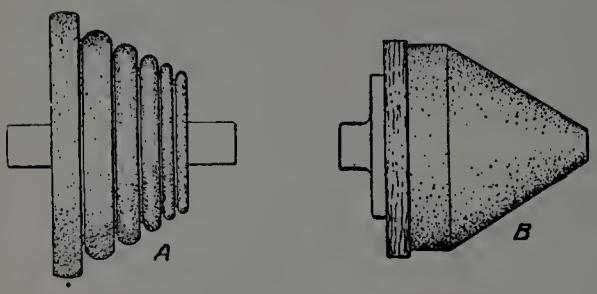


Fig. 272.

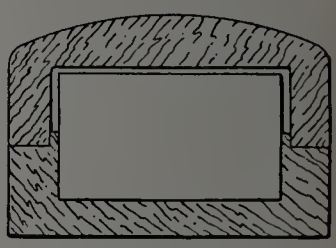


Fig. 273.

gouges, but unsuitable with the smaller, quicker ones. Very often, a small piece of grindstone is rigged up in the lathe, and turned to take gouges of various radii (Fig. 272, A). Or a conical stone may be fitted to the lathe (Fig. 272, B), or a lead lap, turned conical, and charged with emery powder, is used for the paring gouges, and irons of hollow planes. Dry emery must, however, be used cautiously, to avoid risk of overheating the steel.

For woodworking, as also for the finer metal-turning, the tools must be sharpened in addition to being ground. This is done upon an oilstone, or hone, lubricated with oil. Fig. 273 shows the stone in cross section in its stock, with the best method of fitting the cover. The result of sharpening is this: a thin film or strip of the metal is abraded, and turned over by the friction of the tool on the stone, until a new keen edge of metal is obtained. Hence it is necessary that the iron should be rubbed until there is

a sensible "wire edge," as it is termed, or until a burring over of the metal is obtained, quite perceptible to the finger when it is brought along the face up to the edge. But this burr is all rubbed off the back, or chamfered facet of the tool—never off the face—the latter being simply passed over the stone for the purpose of thrusting the burr backwards, and so assist in its detachment. Hence the tilting of the faces of plane irons and chisels is not only detrimental to their efficacy, but unnecessary for purposes of sharpening. The wire edge, too, is seldom entirely removed by sharpening, and its complete separation, when desirable, is effected either by stropping it on a leather strop (Fig. 274), or by drawing the cutting edge once or twice along the edge of a piece of hard wood. The strop in Fig. 274 is made by gluing sections of leather belting into a stock, similar to that of a hone.

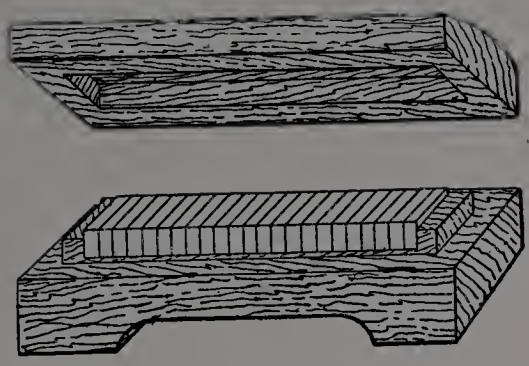


Fig. 274.

Grinding should be economised as much as possible. To grind a tool very thin, and then to commence sharpening at an obtuse angle, wastes the substance of the steel, as also does continuing to grind after a perceptible burr is produced, or grinding lop-sided, and then having to reduce the opposite side in order to bring the tool square.

With a chisel newly ground, the angle for sharpening should be sensibly equal to that at which it leaves the grindstone, and the longer it remains at about that angle the better.

It is practically impossible to sharpen exactly at the ground angle (unless hollow ground on a small stone, like a razor). There must be a very slight amount of elevation, in order to get a clean and straight facet.

A paring gouge must be sharpened upon a slip of hone, either mounted in a block, in oilstone fashion, or more commonly held in the hand, while rubbed on the gouge, the latter being rested against the bench edge.

Outside gouges are sharpened on the oilstone, being rubbed up and down, though not precisely like a chisel. The gouge is held

sideways, and rotated in the hand, through the arc formed by its cutting edge, being moved longitudinally meanwhile. The slip then removes the burr from the hollow face.

Fig. 275.

Oil slips (Fig. 275) are in such constant request for gouges of both kinds, as well as for hollow, beading, and moulding planes, and spokeshaves, that several are necessary to the workman, three or four at least. One slip will do duty for four sweeps, its two edges permitting each of two sweeps, one at each end, merging at the centre. Among oilstones and slips there are none better (Turkey, of course, excepted) than Charnley Forest, as they are called. They come from Charnwood Forest,

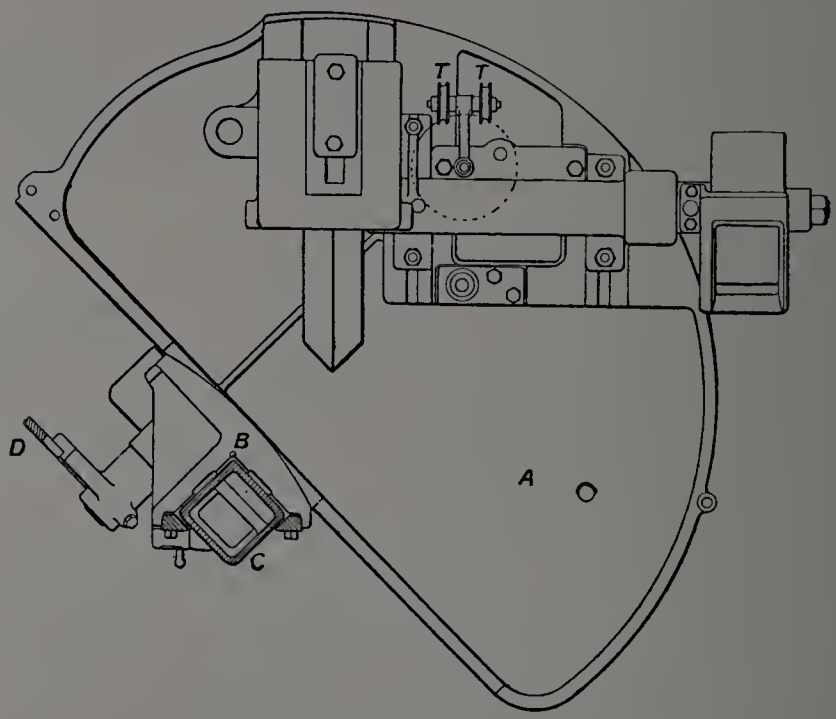


Fig. 276.

in Leicestershire, and are so uniform in quality that a stone of that kind can almost always be depended on.

The conditions to be fulfilled in a precision grinding machine for common tools for lathe, planer, slotter, &c., must include those, which govern the shapes of all tools used—straightforward, bent, round-nosed, and prismatic, with varying clearances and varying degrees of top rake. To fulfil these entirely, the tool-holder must be capable of universality of movement, easily adjustable, and

having provision for precise measurement of angles; and the more nearly a grinding holder fulfils these conditions, the better are its claims to favourable consideration. Two primary circular movements must be embodied: that for plan angles, and that for clearance angles. Besides this, a traverse motion of the tool which is being ground against the wheel is essential, in order to present fresh facets constantly, and so prevent glazing. Another is an

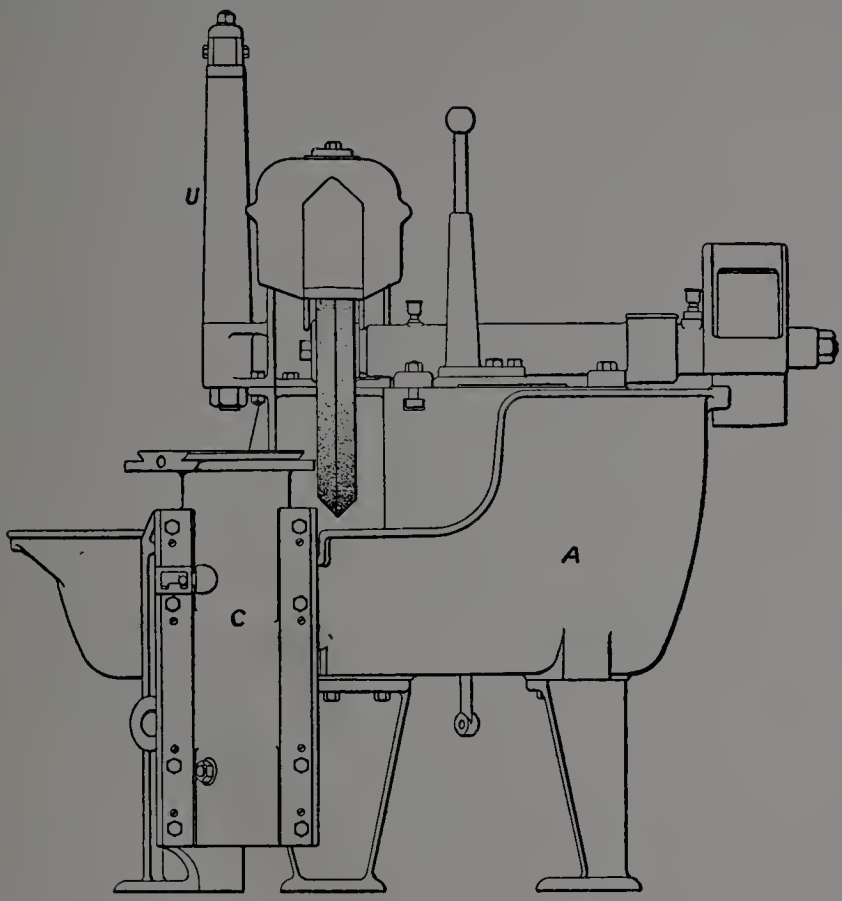


Fig. 277.

oscillatory movement for round-nosed tools. Then another is required to maintain the face being ground in contact with the wheel, as the face is reduced.

There are two successful American grinding machines for common tools—the Sellers, the older; and the Gisholt, more recent. There is a resemblance between the two in regard to the use of circles of division for adjusting the tool angles to be ground, but the details of construction are entirely different in each case. In

each the tool is clamped upon its base, precisely as it would be in the clamp of the rest or of the tool box, and in each its angles are all ground without altering its position in the holder.

In the Sellers machines there are two designs embodied: one, the larger size, in which a wheel is used having two grinding edges, of vee shape, the two meeting at an angle of 90°; the smaller machine having a wheel of ordinary plain disc shape. The large machine deals with heavy tools, the smaller machine takes tools with shanks up to $1\frac{1}{2}$ by 2 in.

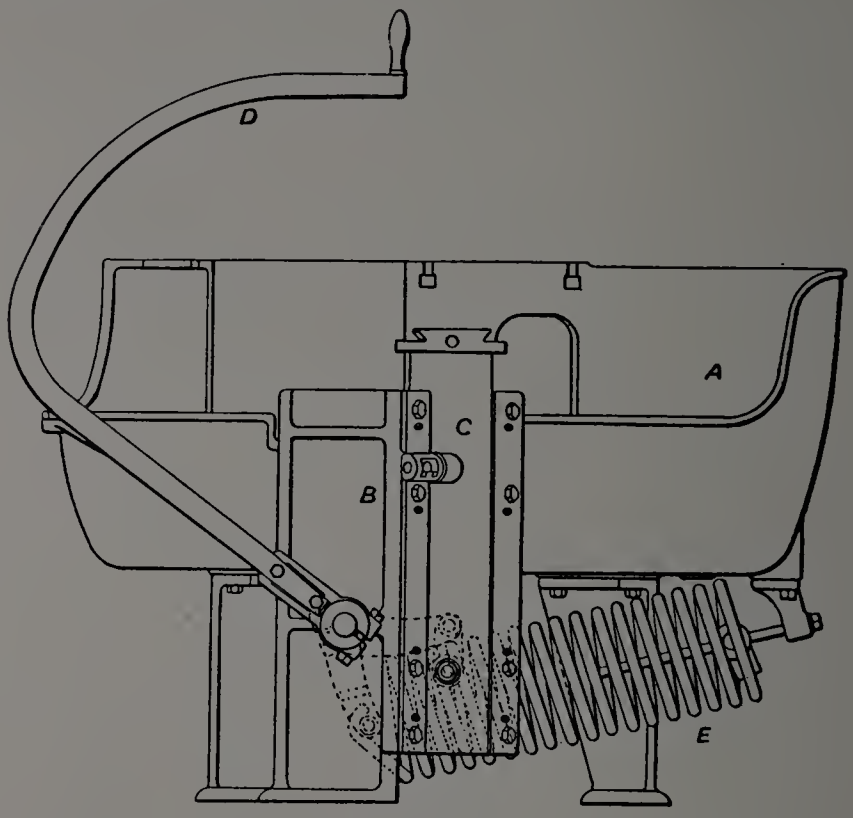


Fig. 278.

The illustrations, Figs. 276 to 285, show the No. 1 tool grinding machine of Messrs William Sellers, Inc., of Philadelphia. It is a universal machine, covering all the tools used in a shop on lathes, planers, shapers, slotters, &c., and taking tools, the shanks of which do not exceed $2\frac{1}{2}$ by 2 in. in cross section. The machine is adapted for grinding both straight-faced tools, and those with curved faces. The wheel, of vee section, is convenient for grinding different surfaces, and for producing smoother work. The general mechanism is as follows:—

The entire machine is self-contained, being carried on the tank-stand A. On one side of this there are deep angular sliding ways B, which carry the stem C of the main tool slide. This is reciprocated vertically by the handle D, and as the mass of the moving parts is counterbalanced by the spiral spring E, little effort is required to effect the movements. The tool chuck can be rotated in a horizontal plane about the vertical axis *a*, Fig. 279, parallel with the tool shank, and set by the graduated arc F, and *a* vernier. It can also be rotated about the horizontal axis *bb*, Figs. 279 and

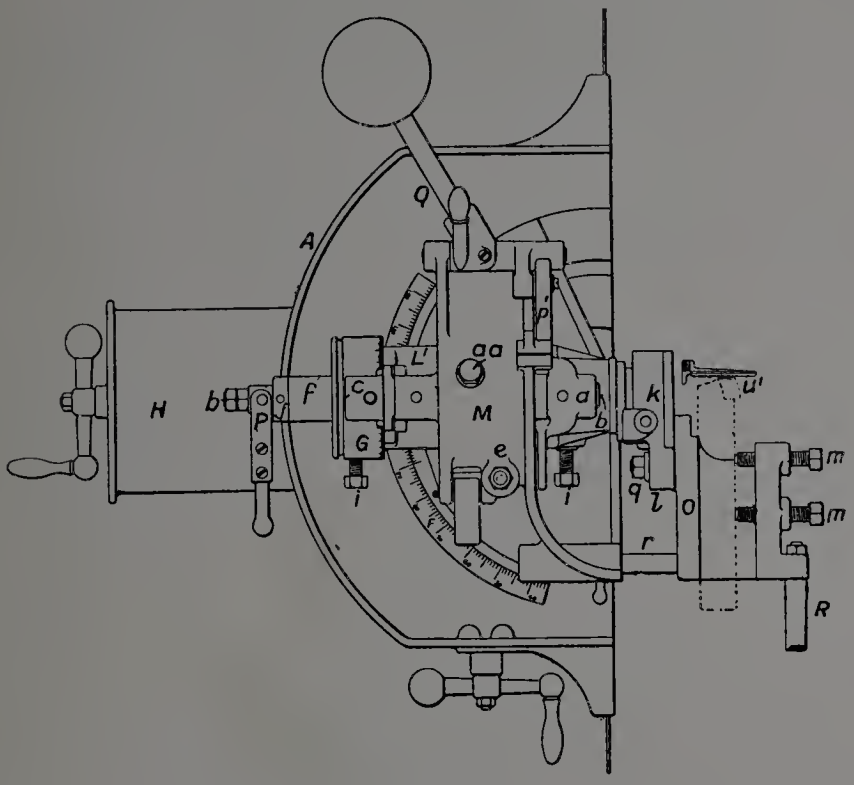


Fig. 279.

280, and set by the graduated disc G. There are besides two slides H and J, at right angles with each other, by which the tool chuck can be moved parallel to the tangent planes of the two grinding surfaces of the wheel. There are two chucks, one for grinding straight-faced tools, the other for those having curved faces, by means of a former, and a device for grinding formers, all of which are shown in these figures, which we will now consider in detail.

The case of straight-faced tools, or those the cutting edges of

which are produced by the intersection of plane surfaces, is dealt with by the sliding movements, and circular adjustments just

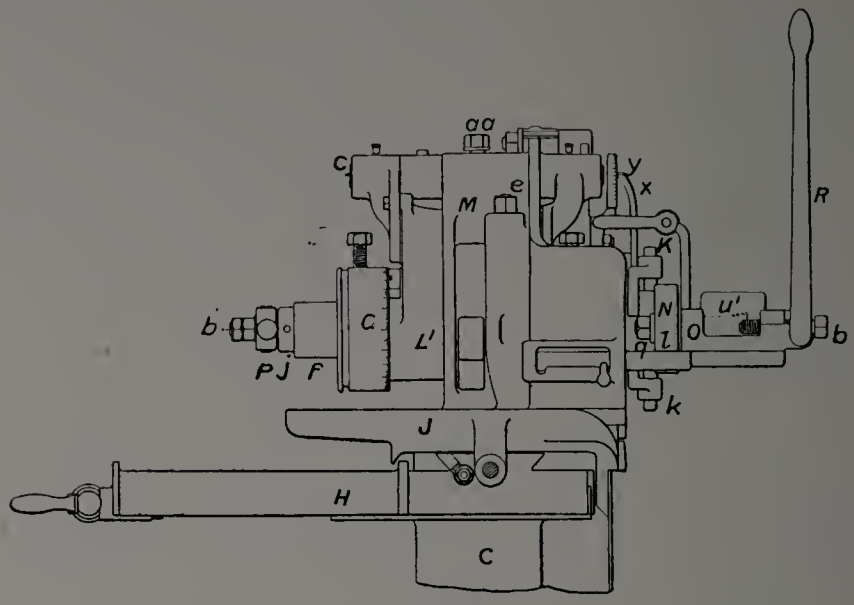


Fig. 280.

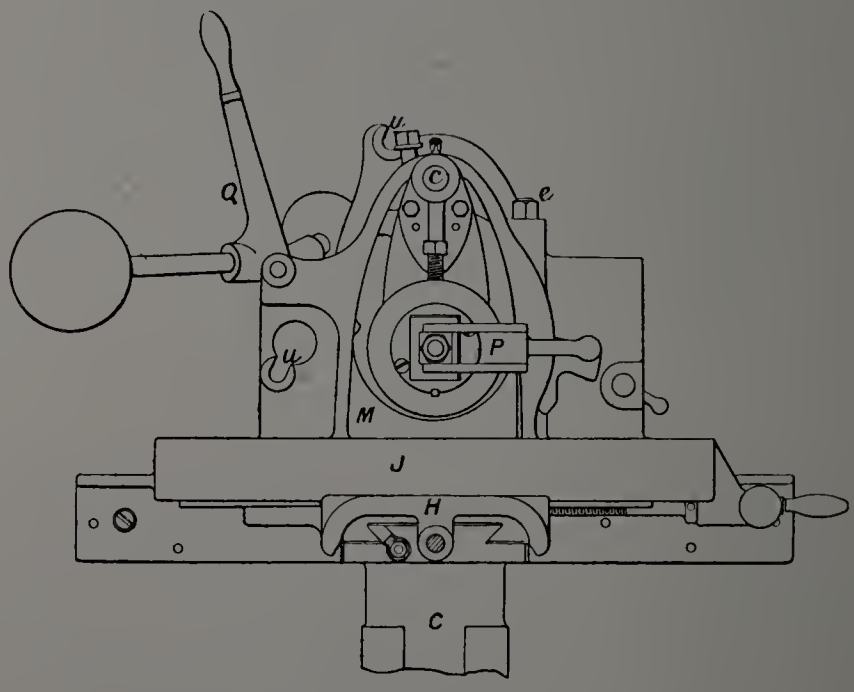


Fig. 281.

enumerated. K, Fig. 282, is the chuck used for these, fitting and revolvable in the bearing L.

The case of curved-nosed tools involves more elaborate mechanism, as follows:—

The bearing, L′, is a vibrating one, being a portion of a swing-

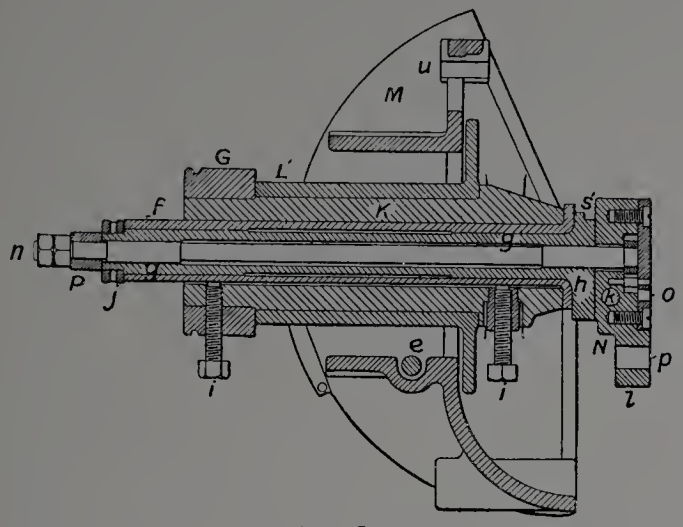


Fig. 282.

ing frame L suspended on the shaft *c*, Fig. 284, in the supporting bearing M, which of course partakes of the motions of the slides just now mentioned; *e* is the clamping nut, by which the bearing M and its swinging frame is clamped in relation to the quadrant

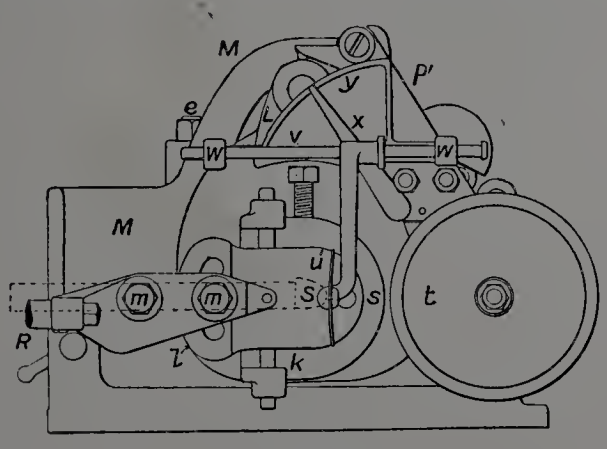


Fig. 283.

F. By swinging the bearing, the axis of the oscillating chuck is vibrated toward and from the grinding wheel.

The plain chuck K, revolvable in the bearing L′, and adjustable by the graduated disc G, and clamped by the screw *aa*,

encloses a sleeve *f*, which is a journal for the bearing *g* of the oscillating chuck, the upper end of which is expanded to form a head *h*, the opposite end being retained by a screwed collar *j*, by which endlong motion is prevented. The sleeve is clamped by the two set screws *i*, *i*, seen in Figs. 279 and 282.

The tool-holding mechanism is clamped indirectly to the head *h* by an intermediate slide rest N, provided with a traverse pin *k*, and with a graduated edge at *l*. N receives the tool chuck O, in which a tool is seen clamped by the screws *m*. This slide rest is capable of traverse movement along the pin *k*, by means of the central locking bolt *n*, as follows :—

The bolt *n* has a head at one end fitting in a recess in the slide rest, and at the other, is furnished with a hinged handle P, with cam-shaped cheeks, which either press against the end of the journal *g*, or are released therefrom, by moving the handle P up or down on its pivot, so locking, or releasing the rest N on the head *h*. Or, on release, the bolt *n* can be turned on its axis, by which movement teeth cut on its head engage with teeth in the rest, and so slide the latter in one direction or the other along the pin *k*. The tool jaw O is pivoted in the hole *o*, and clamped in the curved slot *p* by the bolt *q*. A pin *r* locks the jaw O in a horizontal position, when placing, or removing the tool. But when grinding is being done, the pin is drawn back, allowing the jaw to oscillate freely about its axis in the vibrating bearing L, through about 180°, for presenting the contour of the round-nosed tool to the grinding wheel. And this brings us to the action of the former plate shown at *s*, Fig. 283, and which fits into the recess *s'* of the head *h* of the journal *g* in Fig. 282, being checked therein with a rectangular notch. *s* is in contact with a roller *t*, carried on a stud in a stand *p'*, Fig. 283, fitting by two bolts into the main bearing M, one of the bolt holes being seen at *u*, Fig. 282, and both in Fig. 281.

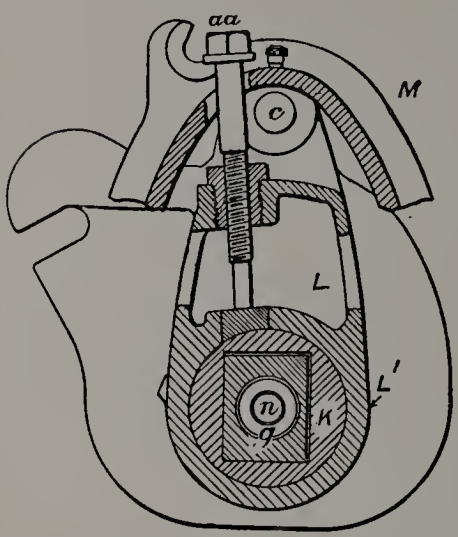


Fig. 284.

The counterweighted lever Q is employed to press the former

plate *s* against the roller *t*, and it holds the plate against the roller with sufficient force to ensure the vibrating motion of the chuck. The tool, pinched in the jaw O, is rotated about the former plate *s*, by the handle R, and its shape will depend, subject to the shape of the plate, on the relation which its position inwards or outwards, bears to that of the former *s*, and will range from an exact counterpart of the former, but on a reduced scale, to a pointed round-nosed tool.

An indicator *u'* is provided to determine the distance to which a tool S should project beyond the axis of the oscillating chuck when clamped in its jaw. Its curve corresponds with that of the average curvature of the grinding wheel. It is attached by an arm to the shaft *v*, which turns and slides freely in the bearings *w*, *w*.

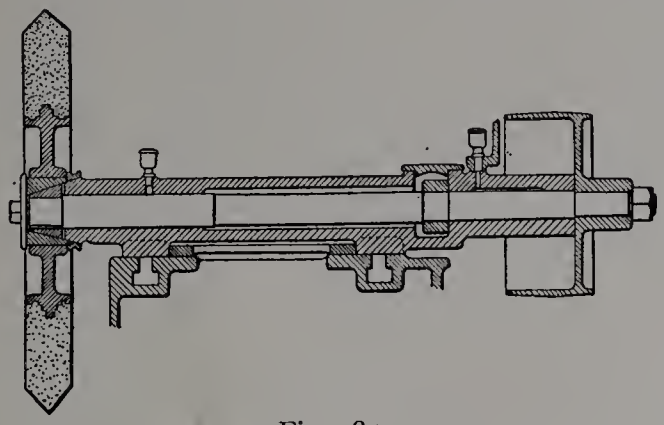


Fig. 285.

A weighted lever *x* presses against the boss of *u'*, and its finger indicates divisions on the arc *y*, and thus, the distance out at which the tool makes contact with the indicator. In this way a tool can be set, leaving the slight allowance for grinding off, or when a tool has been ground, the number can be read off, and used as a guide for grinding similar tools at any other time.

The wheel head is shown in section in Fig. 285. It is adjustable bodily on tee slots in a plate cast with the tank-base of the machine. A centrifugal pump is enclosed in the tank, driven by the pulleys T. The pillar U carries a light crane used for changing wheels on the spindle.

Messrs Sellers have prepared charts, giving the most approved angles and clearances for various cutting tools, together with particulars of what formers should be used, and position of index

finger to be set. A drawing (Fig. 286) shows typical round-nosed tools, both straightforward, and bent, with the angles marked.

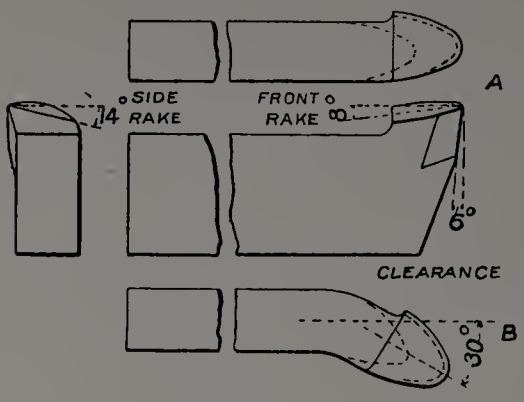


Fig. 286.

In the Gisholt grinder there are the two movements of rotation: that in the horizontal, and that in the vertical plane about the axis of the tool. The frame which carries the circles and the tool-holder, shown in Fig. 287, is carried in the pan of the machine, the whole being capable of oscillation in a vertical plane, in order to permit of the traverse of the tool against the emery wheel during grinding. The oscillation is effected through a large arm of circular section, which is fitted into a boss in the supporting column, the emery wheel having its arbor in the top of the column, and it is easily effected by the workman through a lever attached to the pan. To move the tool forward, as grinding reduces its face, the pan, with the tool-holder, &c., is traversed by a hand wheel and screw, operated by the left hand of the attendant, while the right hand is engaged in manipulating the lever. The emery wheel used is hollow, and conical in section (Fig. 288). Its front face is used for grinding, it is protected by a hood; and a water pipe, grinding chart, &c., are attached. The holder (Fig. 287) permits of the following adjustments for angle: In the horizontal plane it can be rotated through about 320°, which gives plan angles of tools, including those which are bent to right or left hand; in the

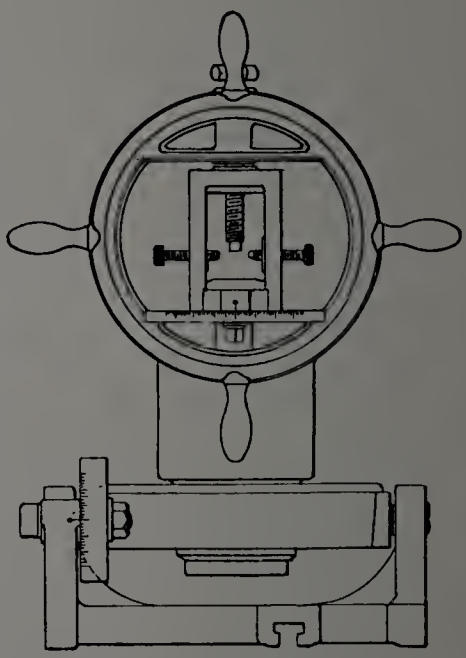


Fig. 287.

vertical plane the tool can be rotated through a complete circle round the tool axis, which allows of grinding the top, and both sides. There is also provision for a movement of the tool to 30° on each side of the centre line of the holder, to bring the faces of bent tools parallel with the face of the emery wheel; and another of 15° on each side of the horizontal, specially for grinding the clearances on threading tools.

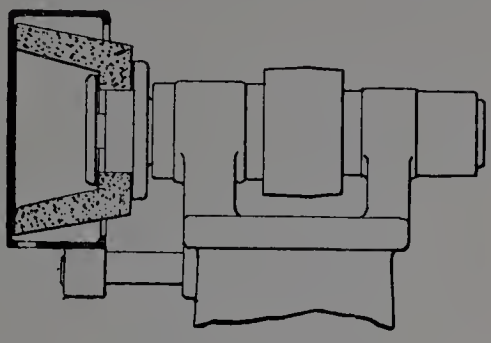


Fig. 288.

The problems of mechanically grinding single-edged tools are of a different character from those which arise when the multiple-edged tools have to be ground and sharpened. The latter have given rise to some scores of different kinds of machines of universal character, that is, capable of grinding all the shapes of milling cutters, reamers, taps, drills, &c. We cannot give details of these, but must simply illustrate one machine of this kind, and give a few examples of how the work is done.

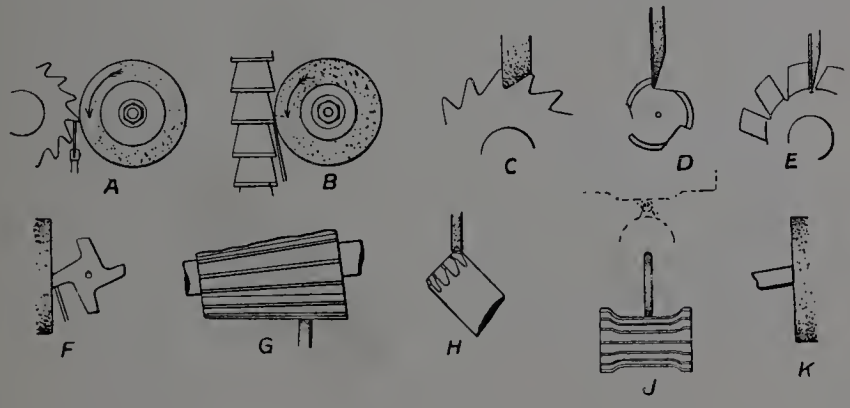


Fig. 289.

The work which a machine must be capable of performing includes the following operations:—Grinding the teeth on plain parallel cutters, with the grinding wheel axis parallel with the cutter axis, Fig. 289, A, a tooth rest being used to keep each tooth at the correct height as it is brought round for operating on. Grinding the sides of cutters, when teeth are formed upon them, as at B. Deepening the flutes, or cutting them from the solid, may be done

as at C, using a wheel having its edge formed to suit the job. This is an alternative to milling. Taps are sharpened as at D, using a cup wheel to grind the cutting face. A similar class of work is shown at E, but on backed-off, or relieved cutters, which are thus sharpened without changing their form. Reamers are most conveniently sharpened as at F, where a cup wheel travels along the edge, and leaves a flat surface, the suitable amount of clearance being obtained by tilting the reamer down as shown. Tapered, or bevelled cutters are ground by angling the table of the machine, or the wheel head, to suit the required bevel, as at G. An extreme case of angling is shown at H, being a rose reamer, or broach, having its end teeth being touched up. Profile grinding occupies a large place, and many machines are fitted with attachments for shaping cutters with irregular edges, for milling special forms of work. The principle in all these, however, is that shown at J, either the wheel head, or the cutter slide being controlled by the motion of the tracer wheel seen, which is held against the former plate, of appropriate profile, and so produces the identical profile on the cutter. Some types of machines have a pantagraph device, for profiling cutters either larger or smaller than the former. The grinding of spiral toothed cutters presents no special difficulty, many of the above-mentioned cutters being made of this kind, as well as straight toothed. Either an ordinary tooth rest is employed, against which the cutter teeth are slid, or a spiral head is fitted to the machine, giving the desired twist to the cutter as it is being ground. Knife, and shear blades are ground by simply presenting their edges at a suitable angle to a cup wheel as shown at K. These examples do not exhaust the different methods of grinding cutters, but they are representative, and most other ways are modifications of them. In addition to tooth grinding proper, machines are adapted to certain preparatory work, which must be done, as grinding out the holes true in the cutters, so that they shall fit their mandrels accurately, also facing the sides of cutters and washers, ensuring true bearing faces. The arbors or mandrels are also trued up between centres, so that a tool-grinding machine is really a

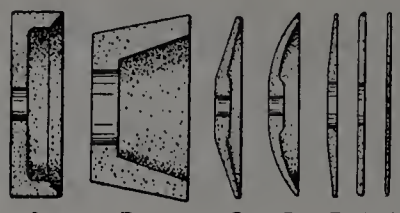


Fig. 290.

cylindrical grinder as well, a pulley being provided for driving the work.

The most generally useful forms of wheels are shown in Fig. 290, the first four types, A, B, C, and D, being cup wheels, and used more often than any other forms. A and B are wheels of heavier type than C and D, the latter being employed for the most delicate work, for which A and B are not so well adapted. E, F,

Fig. 291.

and G are thin wheels, used for sharpening of various kinds, including saw teeth. Wheels like G, but wider, are employed extensively for cylindrical grinding of arbors, and similar plain work. It is impossible to say, however, that any one wheel is suitable for one class of work only, because all are used in turn by different grinders, according to the ideas of the workmen.

Fig. 291 shows a universal machine by Messrs Alfred Herbert,

Ltd., of Coventry, which embodies all the essential features of a good grinder. It is suitable for heavy as well as light grinding. The basis of the framing is a circular column, round which the tables can be slewed to present the work to the wheels in any desired attitude. The tables are raised or lowered by hand wheel, bevel wheels and screw, and they are fed in one of two ways, either quick or slow, for coarse and fine adjustments; for the first, the hand-wheels are turned, and actuate a pinion and rack direct, for the second, a worm is thrown into engagement with a wheel on the pinion shaft and driven by a small hand wheel, seen in the photo, thus producing a delicate and slow motion for grinding. The top table swivels for grinding angular work, and is clamped where desired. Several classes of work may be done with the headstocks provided on the table, from grinding between dead centres, to overhanging arbor work, and circular grinding; a dividing attachment is included for grinding flutes, machine relieved cutters, &c. A universal swivel vice may also be held on one of the heads, for presenting pieces of irregular form, or pieces at any angles desired. The wheel head carries two wheels, one at each end of the spindle, for various classes of jobs, and a distinct high-speed attachment is located at one side, carrying small wheels for internal grinding, and driven by friction wheel from the main spindle. A feature of the machine is that a liberal supply of water can be flooded on to the cutters, enabling them to be kept cool under heavy cuts. A centrifugal pump at the base of the machine forces the water up through the flexible pipe, direct on to the wheel, covered with a guard, and trays are provided which catch, and direct the water downwards to the tank again, where it is strained, and pumped up again.

SECTION VI.

TOOLS FOR MEASUREMENT AND TEST.

CHAPTER XIX.

Standards of Measurement.

Definition—Rule and Gauge Measurement—Standards—Temperature—Interchangeability—Limits of Accuracy—Early English Standards of Measurement—Basis of—Pratt & Whitney Standards—Details—Line Measures, and End Measures—Refined Tests—Rules—Varied Forms of—Use and Wear—Scales—Forms of—Tapes—Rods.

A CORRECT definition of measurement would be, the testing of the dimensions of a piece of work with reference to a standard agreed upon. This would exclude the employment of straight-edges, squares, bevels, or calipers which are used to test mathematical relations. Yet these should certainly be included in any complete account of the methods of measurement.

The testing of dimensions is effected with reference to the standard of the rule or the gauge. Though the latter is derived from the former, the present tendency is towards the increasing use of the last named, at the expense of the first. The rule is seen and used less, and the gauges more. But each has its own definite place in the economy of the workshop. The common use of the rule is lessened also by the employment of templets and jigs; but these also have, like the gauges, to be derived from that instrument, dimensions being transferred by direct measurement, or more often by the points of compasses, dividers, or trammels.

The great difference between rule measurement, or that taken, and transferred therefrom by the points of compasses, &c., and of gauge measurement, is that the sense of vision is relied on in the first, and the sense of touch in the second. This is a most impor-

tant distinction, because the sense which feels the contact of parts is capable of detecting more minute differences than the eye, unless the latter be assisted by magnifying glasses. And magnification is not of much use unless assisted by the mechanical control of an instrument.

Take a steel rule used by workmen: the finest dimensions are seen to be one-hundredths of an inch, into which perhaps one particular inch only is divided. Now one-hundredth of an inch, though very fine as a visible subdivision on the rule, is one that is seldom worked by when compass measurement is resorted to. It is but the thickness of a compass line, to one side or other of which a man may work in machine tool or vice, and be considered a neat workman in doing so. Actually the sixty-fourth of an inch is the finest rule dimension of which any account is usually taken in the shops, though it is often qualified as being "full" or "bare." Yet one-hundredth of an inch is extremely coarse in any system of gauging, for which in ordinary work it would have to be divided by ten or twenty.

The proper places of these two systems of rule and compass, and of gauging instruments may now be settled. The time is rapidly vanishing when the turner and machinist will check their work by direct reference to the rule. But the liner-out must still employ the rule and compass, or the equivalent templet, which depends for its accuracy on rule and compass. As the work of a shop becomes more highly specialised, the direct rule-and-compass methods give place to the use of templets for lining-out, and of jigs for machining.

There are two kinds of rule measurement, and two of gauge measurement. The rule may be used directly, or the compasses can be used for transference therefrom. The gauge may be movable, or fixed, and each method makes a great difference in results, and corresponds with diverse shop systems.

Into the modern system of measurement many matters enter. In the first place we must take the broad fact that engineering work is international in character, and that this involves a uniform standard of reference for dimension units. The demands are such that a shaft made, say, in England, will fit a hole bored in America; that taps and dies made in any country to a given standard will be exactly alike; that gauges will be depended on within certain limits, irrespective of distance or time. Here, then, the

question of standards comes in, which is a most difficult one, to the solution of which the abilities of the best mathematicians and mechanicians have been brought to bear.

Having the question of standards settled, the problem of temperature has to be grappled with. Since materials change their dimensions with every change in temperature, however minute, and as shops range anywhere between 40° and 90° F., a definite temperature has to be settled on, at which alone measuring instruments shall be standard. Metal also undergoes slow changes which, though negligible, like temperatures, in coarse dimensions, have to be counted on in the very finest measurements. The mechanical difficulties of manufacture increase with refinements in measurement, making the production of standards a task requiring infinite patience and the highest possible technical skill and care. Then, after these are obtained, the work of transferring and reproducing dimensions on various gauges and measuring tools is one that is fraught with difficulty, so that the production of the finest measuring instruments and tools remains the speciality of a few firms.

The greatest impetus to the use of high-class instruments of measurement has been due to the growth of the interchangeable system, for a concise explanation of which, see page 3.

To secure such results without an enormous cost for labour, the work of the machines, and the measuring instruments must be exact, and correlated. The tools must be capable of producing parts so accurately that only by chance or accident will any deviations occur from uniformity in the pieces made. The measuring instruments also must be capable of ready application. And behind all these is the paramount problem of cost, for economy is an essential dominating factor in production. The fallible human element must be nearly eliminated, and the skilled mechanic give place to the machine minder, and the gauger, who may be a mere boy or girl.

In speaking of accuracy, it is as well to observe that no one understands this to mean absolute truth, which is impossible of attainment. The term is relative only, and its degree, or the measure of approximation to truth is different in different classes of work, and to these varying degrees some measuring instruments are adapted. In some classes of rough work one-hundredth of an inch is a sufficiently fine approximation; in others one-thousandth is too coarse. Now one excellent feature of the modern system is

that the degree of accuracy permissible in any given class of product is predetermined, and embodied in the setting-up of machines, and in the measuring instruments used, so that when once fixed up by a trained mechanic or toolmaker, no further skill is required for the operation of the first, or the application of the second. Since, also, no machine, however carefully fixed up, can be depended on to produce a large number of similar parts precisely alike, the variation from exact accuracy which is permissible is also predetermined, and embodied in the measuring instruments used, so that a boy or girl when gauging by the sense of touch can tell in an instant whether a piece is above or below the limits which are permissible.

It is clear that this system of interchangeability is not suited for all classes of work, but that to be economical and successful a very large number of similar pieces must be required. This would appear to lessen its value, and to bar its use in many shops that chiefly handle general work. So it does, but not to the extent which may be supposed. The introduction of a good system is better than working without system, in a heterogeneous fashion. There are few shops in which the work is of so very general a character that there are no parts of mechanisms which do not recur in large numbers. The commonest are small screws, bolts, studs, and pins—just the work for special machines and methods of measurement. But when once a system is introduced, it tends to extension, and to applications not anticipated, and therefore when a firm can see its way to make a good system fairly pay its way, it is best to take it up.

The earliest measurements were derived from well-known objects. Every one remembers "Three barleycorns make 1 inch; 12 inches, 1 foot; 3 feet, 1 yard." By Statute 17 Edward II., 1324, it was enacted that "Three barleycorns, round and dry, make 1 inch; and 12 inches, 1 foot." Thirty-six barleycorns would therefore make 1 foot, but they would not be so reliable as twelve bronze halfpence placed edge to edge, which give that measurement very exactly. That standard, if it may be so termed, remained lawful for five hundred years, until in 1824, by the Act 5 George IV., cap. 74, it was declared that a yard bar made by Bird in 1760 was "declared to be the extension called a yard; and that the same straight line or distance between the centres of the said two points in the said gold studs in the said brass rod,

the brass being at the temperature of 62° by Fahr. thermometer, shall be and is thereby denominated the 'Imperial standard yard.'"

It must not be supposed that the legalisation of the standard coincided with an awakening to the necessities of a better system. In this, as in other matters, the Legislature but followed the leading of the Time spirit. In 1791 the French Commission adopted the length of a ten-millionth part of the quadrant of the earth's meridian as a metric basis. Curiously, too, this coincided almost exactly with the length of a seconds pendulum, researches into the beating of which had long engaged the close attention of physicists, since the time when it was proposed by Huyghens in 1670, and Picard in 1671, as a basis of measurement. The length of the seconds pendulum, 39 in., is not so constant as to be a reliable standard of reference, because of the influence of minute errors due to the temperature, latitude, and weight of air. Later proposals have been to utilise as a basis some unalterable minute measurement such as the length of a wave of sodium light.

But proposals of this kind will not now find favour, because the original bases, though demonstrated since to have been inaccurate, are now crystallised in standard bars carefully preserved in all civilised countries for the purpose of reference. The history of these bars is a tribute to the patient and loving labour of many men, to whom the whole world owes much, yet whose names are little known outside the world of scientists and scientific engineers. All the measuring instruments used to-day are referable to some original standards, not directly, but through intermediate or secondary standards derived from them. The original standards are only accurate at a certain temperature at which they are maintained. They are mostly in charge of public bodies, though some few of the leading manufacturing firms have exact copies. Nothing is ever allowed to touch the originals for the purpose of transferring dimensions. But microscopes and light reflections of a most elaborate character are the means by which transferences are effected.

The existing English standards are the result of the labours of Sir Francis Baily and the Rev. R. Sheepshanks. The original bar referred to just now as having been legalised by Act 5 George IV., and which had been constructed by Bird in 1760, was destroyed by the fire which consumed both Houses of Parliament in 1834. When an attempt was made to restore it by reference

to the seconds pendulum—a contingency which had been provided against by the Act of 1824—it was found to be impossible, in consequence of the errors inseparable from the method. Consequently the new yard was restored laboriously with reference to various standards—five in number—in existence, none of which was precisely alike. The result is Bronze No. 1, which is kept in the Houses of Parliament. It is composed of copper 16 parts, tin $2\frac{1}{2}$, and zinc 1, measures 38 in. long, 1 in. wide, and 1 in. deep, and the graduations are marked on gold plugs sunk into the bar 36 in. apart, the top faces of the plugs being half way down the thickness of the bar. The reason of locating them so was to neutralise the difference in length which would be caused by flexure of the bar. About forty-four copies were made, which are in the possession of various public institutions at home, and of foreign Governments. They were legalised by Act of Parliament, 30th June 1855. All these are made of the same class of bronze, termed "Baily's metal," so that they would all expand at similar rates, and corrections for temperature could be made alike in all. The temperature at which the standard yard is measured is 62° F. There is therefore no such thing as a standard inch. The standard is the yard, which has to be subdivided by manufacturers. The standard French metre is termed the metre of the Archives. It is made of platinum, and is standard at 0° C., or 32° F.

The man who handles a foot rule knows little of the labours which have been accomplished ere he could obtain that rule. Before its manufacture was possible, the highest labours of physicists, mathematicians, and scientific mechanics had been brought to bear for more than a hundred years past on the problems of measurement, and on those involved in the materials used. Differences of temperature, differences in the coefficients of expansion of materials, differences in density, hardness, or degrees of annealing, differences due to flexure, errors in observation, the fallible human element in making and measuring, and much else—all these problems had to be attacked, and the errors ever insuperable therefrom reduced to the last minimum.

The Pratt & Whitney Company, of Hartford, Conn., derived all their measurements first hand from the imperial standards, for the reproduction of which they engaged the services of Professor Wm. A. Rogers. As the imperial yard of Great Britain, No. 1 of Baily's metal, could not be available for ready reference by an

American firm, the "Bronze II." of the United States was selected. This was presented to the United States in 1856, and was stated to be standard at 61.79° F. By reference to this, several Pratt & Whitney standards were prepared for end measure, and line measure, the details of the preparation of which are much too lengthy for publication here. They include bars of bronze, of tempered steel, and of annealed steel. The lines are also variously marked. In one of the bronze bars 41 in. long, 1 in. wide, and 1 in. deep, the lines are marked on polished gold plugs inserted in the bottom of wells sunk in the bar to the depth of half an inch, at intervals of 12 in. In another bronze bar of the same length, platinum-iridium plugs, $\frac{1}{16}$ in. in diameter, are inserted flush with the surface at various distances, while in one of the tempered steel bars 40 in. long, $1\frac{1}{2}$ in. deep, and $\frac{3}{4}$ in. wide, the surface is polished for receiving the graduations. An annealed steel bar of nearly the same dimensions has tempered steel plugs inserted. These bars were prepared by the Pratt & Whitney Company at their own shops, and the depth was found to be so nearly parallel that the surfaces remained in focus under the microscope of the comparator, when the microscope was moved along the whole length. Microscopists will understand the severity of this test.

The flexure of such bars, even though slight, would of course alter the lengths marked upon them, and it is found that two points of support ensure better results than attempting to support the bars along their whole length. It is found that if the points of support are placed at the ends of a bar 41 in. long, the change of length due to flexure is over one-thousandth of an inch, which is a very coarse degree of error. This is the reason why in some standards the defining lines are traced on gold plugs sunk to the level of the neutral plane of the bar, where the effect of flexure is eliminated. But then difficulty arises in reading subdivisions. To prevent flexure, points of support must be placed at a distance from the centre equal to half the length of the bar, divided by the square root of 3. If the supports are placed nearer the centre, the upper surface becomes convex; if nearer the ends, the upper surface becomes concave.

Temperature affects the standards so greatly that extreme precautions were necessary when transferring or comparing dimensions. The temperature in these bars was kept as near

62° F. as possible, and lines were drawn in some cases a thousandth of an inch apart, the middle line of a group forming the actual defining line. In this connection the coefficients of expansion of the various mixtures used came in for study. In order to ascertain these, lengthy periods of observation were found to be necessary, during which changes in length under a varying temperature had time to become permanent. Thus, mass and conductivity both affected the result, retarding or accelerating change. Changes of considerable magnitude were often found to have taken place in the relative lengths of two bars made of different materials and of large mass, even though the reading of the thermometer placed upon the surfaces remained constant. The presence of a visitor will cause a rapid change of temperature in a bar having a large area and a small mass. And even if the mass is large, when there is direct contact of the hands, an instantaneous change in length will follow. But if a shield of thick writing paper is interposed, no effect will be produced for several minutes. Comparisons were sometimes made in liquid glycerine, but generally in air.

In grinding end standard measures the operation was performed first in liquid, to within a thousandth of an inch, after which comparisons were made with the standard in air, extending over a period of from ten to fifteen days, and at temperatures ranging largely below and above 62° F. After two or three operations and comparisons have been made, the true limit is reached.

The net result of the scientific and mechanical work expended upon them at enormous cost is that P. & W. 1 is 53 millionths of an inch longer than the imperial yard, and P. & W. 2 is 36 millionths of an inch shorter than the imperial yard at 62° F. P. & W. 3 is 227 millionths of an inch too short.

The importance of temperature in standards may be illustrated by the fact that of the forty copies of the British imperial standard yard made for presentation to different Governments, only two are standard at 60° F., though all are made of the same alloy—Baily's metal. But as the coefficients of expansion are uniform, comparisons of these can be made at any temperature, which could not be done with materials having different coefficients. Thus, if a bar of steel were compared with one of Baily's metal, and both were standard at 62° F., they would not be alike in length at

72° F., because the brass would expand at a higher rate than the steel.

Having a bar ruled correctly and within only some millionths of an inch of absolute accuracy on its total length, this bar is used for the derivation of end measures. So that the end measure, and the test contact are derived from line measure. This might seem almost to contradict the statement that in the shops the gauge system is a more accurate one than the rule system. But the methods of the shop do not permit of the use of microscopes, and the other appliances which form part of the readings and methods of transference of the comparator.

An important feature in the production of standards for measurement is that once the ruled bar is made, it is never handled or touched in the transference of dimensions from it to the shop standards. How this is done cannot be explained in a sufficiently lucid manner without drawings of the machine—the comparator—by which it is accomplished. But the result is that any number of copies of dimensions can be transferred without the slightest wear on the original taking place. The only possible change which it could undergo would be that due to internal strains in the material, which is eliminated by careful annealing at a temperature above that of any temperature due to climate.

The grinding of end measures is done by special machinery by the aid of a special fixture, the block to the ground sliding over a plane surface, in the centre of which is a copper plug charged with emery or diamond dust. Measurements are taken from time to time, and great care is exercised to have the temperature to correspond with that of the ruled bar when making these measurements.

The practical results are these: a number of end measure pieces of various lengths are laid in a groove planed in a massive block of cast iron. One piece is clamped down to form an end stop, and when the pieces—seven or nine, or other numbers as the case may be, which go to make up 12 in.—are laid down, another piece is laid down and clamped at the other end. Then the end stops are readjusted until a $\frac{1}{4}$ in. end measure can be just moved easily between them, almost by its own weight. To prevent contact of the hand with this, and transference of its warmth, it is held by a slip of wood inserted in a small hole in the piece. Then the pieces are removed, the end stops remaining,

and another set taken and inserted, the precaution having been taken of laying them on the cast-iron block until they arrive at the same temperature. The insertion of the $\frac{1}{4}$ in. piece then indicates by its slack or tight fitting the difference in length between the sets If a difference occurs, this, divided by the number of pieces, gives the average for each piece. But to ascertain the exact location of the maximum error each piece can be re-tested by the standard bar.

We will now take up the consideration of the various instruments which are derived from the standards.

The common rule has shared in the advances which have been made in the practice of recent years, so that with regard to this instrument the workman, and machinist is much better equipped than formerly. He not only has a much larger selection of common rules, but a wider range of graduations. Rules are made in various lengths, widths, and thicknesses, tempered, and flexible, so that they can be used in narrow spaces, or bent round curves, and to read in English, or metric divisions, and of square, and triangular section, besides other special forms. And beyond these there are the various applications of the vernier to caliper rules, in which the sense of touch is combined with that of sight, for reading dimensions for which rigidly fixed gauges are unsuitable.

A machinist with only one rule is not well equipped. His principal rule should be divided out chiefly in the measures which he habitually uses, and be of a length most suitable for the class of work which he chiefly handles. It is rather confusing to have a kind of universal rule with all sorts of subdivisions, just as it is to have universal scales, or, as in the case of the pattern-maker, to have both standard divisions, and those also for contraction for iron, steel, and brass, on one rule. Mistakes are liable to occur, and do happen, besides which time is lost in locating the class of divisions required. It is better to have rules divided similarly down the whole of one side, and with four sets of graduations, two on each side, and all in the same class of measurement—inches or millimetres, eighths, or tenths, &c. For instance, tenths, twentieths, and their subdivisions are seldom wanted in our shops; metric divisions are still only used to a limited extent. It is better, therefore, to have the principal rule divided only into eighths and their aliquot subdivisions, and a

separate rule for millimetres, and another for tenths. The principal rule, again, should be no longer than is suited to the general run of work, and is most convenient when it can be slipped into the waistcoat pocket; hence the popularity of the 6 and 4 in. rules. A 12 in. rule means the rule pocket in the trousers, though in working continually at the marking-off table or other fixed location the rule need not be carried about at all.

Then, again, there is a wide choice in the types of rules, apart from the question of their subdivision. They may be wide or narrow, rigid or flexible. Narrow rules are very handy, inasmuch as they fulfil similar functions to depth gauges, as do the brass slides in the slide rules. Thin rules of tempered steel go round curves better than thick rigid ones. Besides these, specially flexible rules are made of spring tempered steel. There are others which are less used, but which help to make up the wealth of rules now offered to the machinist and erector.

Though in these days of gauged work the functions of the rule have been largely invaded, the duties of considerable numbers of men being such that a rule is scarcely ever required or used by them, for the general hand this instrument is as much in request as ever. There is plenty of work for which the gauges, micrometers, and allied instruments are of no service. In all the work of the carpenter, joiner, and allied trades, of the marker-off, of the erector and millwright, large sections of that of the turner, planer, and shaper, and slotter hands, and much of that of the fitter, common rules, calipers, and compasses fulfil the chief functions. By the use of finely graduated steel rules, and fine adjustment compasses and calipers, the greatest volume of the general work of enginers' shops is still done.

The rule, again, is often incorporated with other appliances, notably the common square. From the wooden try squares of the carpenter, and patternmaker, thus divided out, the high-class graduated steel squares have been derived. These are valuable to the marker-off and fitter and to the machine hands. Millwrights and erectors find them of great value in getting heights of centres, simultaneously with squaring up. In many squares the outside edges only of the blade are graduated, as when the stock is thick and the blade thin. This follows the earlier forms; but in the later and more complete squares that are specially made for machinists and fitters, in which the blade and stock are of the

same thickness, one outer and one inner edge is graduated. In some instances all four edges are graduated, an inside and outside edge having similar graduations, and both faces being alike divided.

The slide caliper rules are another application of the common rule. But they render the use of common calipers for the transference of dimensions unnecessary, since the tongue is graduated in addition to the ordinary graduations on the edges of the blade. These are made in different designs, one having a tongue sliding in the body of the blade, another having a slide adjustable along the lower edge of the blade.

The common rule is an instrument that is too often very badly served. It is used to scrape chips and dust off the surfaces of work in machines, to probe the depths of holes and recesses. It is allowed to rust, and then polished with emery cloth. It is employed as a rough straight-edge on castings and forgings, is thrust between joints to see how wide they are apart, sometimes emery cloth is wrapped around it for polishing. And thus the end wears, the edges become rounding, and fine divisions become indistinct. Rule measurement, never the most precise in shop practice, thus becomes unreliable. When the end becomes worn, accurate measurement cannot be started from the end. If the edge is convex, the divisions do not reach to the edge, and then the rule cannot be used by its edge with perfect accuracy.

When the end of a rule has not been worn by long service, or by abusive treatment, it affords a very ready means of taking measurement from, provided there is a shoulder against which the rule can be set, and from which the dimension can be taken. If the measurement starts from an edge, the rule is abutted against a straight-edge or blade of a square set up against the edge. The same method is of course even more essential when an edge is rounded. The Starrett Company make a rule to suit such cases. It has a short return piece or hook at the end, pivoted on an eccentric stud, and which can be removed when not required. Such a rule is valuable for setting internal calipers by, and especially for measuring from internal shoulders in bores, or planed slots with recesses.

The way to use a rule is either on the depth-gauge principle—that of starting to read from the end,—or the edge of the rule is laid upon the work and the dimension read off, or marked from

divisions intermediate from the end. The latter is the safer and the better method to adopt generally. Although the eye has to judge of the coincidence or otherwise of two divisions on the rule in the latter instance, against one only in the former, the finest results are attainable when the lines of division are set upon the work, the rule being held edgewise. Working to the "thickness of a line" is a very elastic expression; it is really a minute amount when the lines on the best steel rules are worked by.

External calipers are set easily enough from the end of a rule; internal ones are generally set from one end, or from an external pair. To set them from one end, the rule is stood on end on a block of metal, as is also the lower leg of the caliper. Or it is set horizontally against a vertical face. It is not easy to get exact dimensions with internal calipers when set on two divisions on the body of the rule, unless the points are narrow and quite true and parallel.

Scales do not come into the hands of the machinist and fitter nearly so often as they did formerly. They are now mainly used in the drawing offices, and pattern shop. The reason of this change is the gradual diminution of the practice of making small scaled drawings for the workshops, to which the supersession of drawings by sun-printed copies has mainly contributed. In the days when drawings and tracings made by hand were in sole use, the supply was limited by their costliness. Drawings and mounted tracings were then made to small scales. Often, all classes of work belonging to the different shops were included in one drawing, or mounted tracing, which went the round of all the shops, and from which selection was made for the work in each department, until at last, sadly dilapidated, and greasy and obscure, it found its resting-place again in the office drawers. Those were the days when the scale was a necessity; $1\frac{1}{2}$ to the foot was very common—$\frac{1}{8}$ in. on the foot rule read 1 in. in the work; 3 in. to the foot, or quarter size, was also common; 1, $1\frac{1}{4}$, and $2\frac{1}{4}$ in. were less used, but 1 and $\frac{1}{2}$ in. were largely employed for general drawings. Hand sketches made on section paper supplemented these drawings—often, in fact, were substituted for them, though not made for scaling by. Now the usual practice is to reserve the small scales for general drawings only, and to make detail drawings and prints for shop use to large scales or to full size, and often

also fully dimensioned though drawn to full size, so that scaling is rendered quite unnecessary.

A scaled dimension is never taken from an end, but is by lines of division only, the scale being held edgewise on the drawing. To avoid this tilting up is the reason for making some scales of triangular section, allowing the reading of the scale to be taken without lifting it up from the paper. In one type the actual faces are lifted slightly from the paper by end pieces, to avoid wearing the graduations.

The forms and materials of scales include those of boxwood, of double convex section, very flat in their curves, or of chamfered sections, the paper scales, and the triangular-shaped ones of boxwood or metal, and some special forms.

The objection to the boxwood scales is that the edges become damaged with wear, that the wood is slightly affected by changes in temperature, and that they are not flexible enough to permit of measuring round curved lines. Paper scales are better adapted to the latter conditions, but they soon lose their graduations unless protected when new with an application of clear varnish. Metallic scales do not wear so readily, but temperature affects them.

Universal scales are undesirable, being a fruitful source of mistakes. A set of scales is properly necessary, each one of which has four sets of graduations, one only on each edge, as $\frac{1}{2}$, $\frac{3}{4}$, 1, $1\frac{1}{2}$ in., or other divisions alike all down one side, and the end ones only subdivided, to permit of reading two scales on one edge, as $\frac{3}{4}$ and $1\frac{1}{2}$ in., and so on.

Steel tapes are used by some classes of erectors and fitters where long dimensions come in. They are useful in locating centres of bearings, for shafting, and heights. In cases where diameters of large dimensions are required, and rods or other objects occupy the central portions, a steel tape is useful for measuring round an external circumference by, and thence deducing diameters. They are also valuable for setting out dimensions for the erection of work of large size.

But in the greater number of measurements of considerable length in workshops, preference is given to a rigid rod of wood, on which the lengths required are marked. Yellow pine, straight in grain and well seasoned, does not shrink endwise to any appreciable extent. To mark off lengths on such rods—end measure-

ment not being as a rule employed—a standard rod is used. If lengths are marked from a rule of 1 ft. or 2 ft. in length, error is certain to arise in the aggregate length, hence the advantage of standard rods. The method that has answered well in the writer's experience is this:—A standard rod is purchased of a mathematical instrument maker, either 5 or 10 ft. in length, divided finely on the first foot, and inch, on a brass plate let into the wood, and having each foot marked on a brass plate let into the wood. This is kept in a box for reference. From this a rod is made for each shop, and from the latter the men mark the lengths they require, or check lengths taken on their working rods. This method is invaluable, avoiding not only slight errors, but also often big mistakes. The principal standard is never worn by use, yet it remains a permanent reference and court of appeal.

CHAPTER XX.

Squares, Surface Plates, Levels, Bevels, Protractors, &c.

Origination of Straight-edges—Care of—Surface Plates—Flexure—Plates for Standard Reference—Large Straight-edges—Winding Strips—Squares—Try Squares—Testing of—Method of Making—Combination Squares—Centre Squares—Bevels—Bevel Protractors—Scale of Chords—Set Squares—Levels—Wear of—Various Forms—Plumb Bobs.

THE straight-edges, squares, bevels, protractors, and spirit levels, though not strictly tools used in measurement, are nevertheless directly and constantly associated with the actual methods of measurement.

The truth of surfaces and the correct relations of surfaces to each other have to be checked, along with their distances apart; and in setting work for tooling or for erecting, the exact horizontal, or vertical truth of surfaces has to be assured. In the construction of these instruments a different set of problems comes in from those which have hitherto been considered. Though in these, as in measurement, absolute accuracy is not attainable, a very close approximation thereto is sufficient for all working requirements.

A feature of the straight-edges, in which they differ from the majority of measuring tools, is that they can be, and frequently are, made in the shops by the workmen. The same remark applies to surface plates. There are two methods by which these can be produced. They are either made, and tested by another edge, or plate known to be true, or they are originated without reference to any existing instrument. Origination is effected by mutual correction of surfaces.

To originate straight-edges, three separate edges must be obtained, any one of which will coincide perfectly with either of the other two. The problem is exactly the same as that of surface dlates. It seems easy to realise such accuracy; it is difficult of

attainment in practice, and it can only be secured by most careful and minute application of the scrape in the final stages of correction.

It is obvious that though two surfaces may be brought into perfect mutual contact, there is not only no certainty, but a great improbability, that they will be true planes, since they may have equal, and opposite amounts of concavity, and convexity, or of general inequalities. But if three surfaces are in perfect mutual contact they must be true planes, since it is inconceivable that they can be otherwise. The method of origination, therefore, is to get three approximately true, either by planing or filing, and then check them in pairs. When two, say Nos. 1 and 2, are tried together and show no light or want of contact between in reversed positions, the third is tried with one of them, say No. 1, in one direction and reversed. These will not agree, and so correction is effected until they do. Then No. 3, thus corrected,

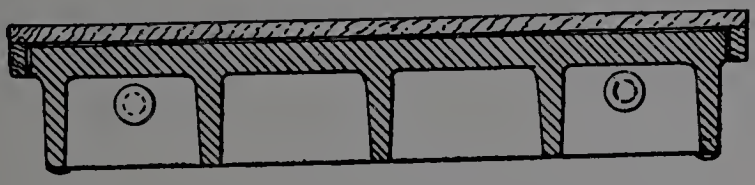


Fig. 292.

is tried against No. 2, and this process is continued until any one straight-edge coincides with both of the other two.

Having once obtained a true surface, however, the work of origination need not be repeated, unless the accuracy of the surface becomes impaired. Generally, in shops, a surface plate forms the standard of reference, or a large cast-iron straight-edge. If these are treated carefully, they retain their accuracy for an indefinite period, but not if they are employed for rough testing of instruments, or if they are allowed to become dusty and dirty. Wooden covers are provided in shops where the necessity for proper care is recognised, and these should be always kept on, excepting when the plates are in use. Fig. 292 shows a section through a plate so covered. The ribbing seen is never omitted from any plate, whether it measures 2 ft. or only 8 in. across. It is necessary in order to prevent risk of flexure, the slightest degree of which would be fatal to the utility of the plate. The arrangement of the ribs is varied in different designs, a very frequent form

being that with diagonal crossing ribs, instead of parallel ones, as in the illustration. Flexure is further guarded against by providing three nibs on the bottom of the ribs, so that the plate has a three-point bearing, which will stand on an uneven surface without distortion. This is most important in large plates, which if provided with four points of support are almost sure to become winding. Large plates are generally oblong in form; small ones are square, or circular. But it is much better to have them square than round, because the edges can be used for squaring from, as in testing try squares.

Another point is that certain plates, and straight-edges should be kept for standard reference, distinct from those which are employed for the common service of the shops. Small plates are generally supplied for the use of individual men, or groups of men, and are kept on the benches or machines. These, of course, cannot be preserved for reference, and their accuracy is bound to become impaired in time. But standards can be retained in the tool-room, or in the foreman's office, just as standard gauges are kept for reference only.

Surface plates are frequently used for work that lies outside their legitimate functions, chief among these in the lining-out of work, and the checking of the relations of pieces of work. A marking-off table, or a plain plate which is planed only, without scraping, is accurate enough for duty of this kind, so retaining the the surface plates for their proper function—that of checking the truth of surfaces which are receiving their final corrections by the scrape.

The foregoing is not the present manufacturing method employed for straight-edges. Scraping must be employed in the final stages for exact corrections of the broad surfaces of surface plates, just as it is in machine slides, work from which no grinding machine has yet displaced the scrape. But there is a great difference between a broad surface and an edge. The small straight-edges which are made commercially are ground true along the edges, and are therefore made cheaply; and there is the advantage that, being ground, they are hardened on the edges previous to grinding, which preserves their durability for a much longer period than if left soft.

Large straight-edges are not made of steel, but of cast iron, and these are nearly invariably finished by scraping. In these large

sizes, length and weight cause trouble by rendering them awkward to handle, and by the tendency to flexure. The typical form made is that shown in Fig. 293, by which these evils are reduced to a minimum. Frequently circular lightening holes are cast instead of the oblong ones shown, and two feet also are often added.

In handling these large tools for testing machine beds and slides while scraping is in progress, it is generally more convenient to suspend the straight-edge in a hoist or light crane, and to lower it on the work for testing, after which it is swung away until required again. This is obviously the only practicable method with heavy machine beds. But where the work being scraped is comparatively small, the straight-edge may be supported, and the work turned over on it for testing.

Contact between straight-edges and the work is tested by red lead, or by sighting between the two faces. Either method

Fig. 293.

enables a workman to detect a very minute departure from coincidence, but the lead leaves a record on the work.

It is not allowable to rub a straight-edge hard on the work, as is sometimes done with the surface plate, the straight-edge being too elastic and yielding, so giving a false test. A straight-edge must be held quite perpendicularly, or normal to the plane of the work, as a little inclination therefrom may falsify results.

A straight-edge is—except in the largest ones of cast iron—made with both edges parallel and true. Either edge can be used, and there is the advantage that a level can always be laid on the uppermost edge. This is valuable when setting work on machines, and when erecting. It is very serviceable both when the surface is a comparatively rough and uneven one, and also when facings occur, across which the straight edge is bridged. It is also useful in order to take a vertical dimension between two faces, one of which stands above or below another, and situated at a distance away. These are cases that frequently occur. Unless faces are perfectly true, it is obvious that the straight-edge, if laid on, will be

thrown out thereby, and the error will be considerable where multiplied by the length of the straight-edge. In such cases the level gives the average or general level of the facing or of the work. Internal faces, bores, &c., can be checked in a similar way.

A particular application of straight-edges is that of two being used, of the same dimensions, termed winding strips, for testing the accuracy or otherwise of a surface intended to be plane. They are laid as shown in Fig. 294, and a sight is taken along their upper edges, when it is easy to detect any minute departure from accuracy. These are employed both by wood and metal-workers, and in the foundry for levelling beds of sand.

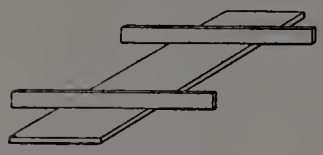


Fig. 294.

Squares may be considered as two straight-edges rigidly set at right angles, since it is essential that the edges be true. So much work requires squaring that these tools are made in two types—the try square, and the set square,—and each, in several sizes, becomes a necessary portion of the equipment of a workman both at bench, vice, and machine.

A try square generally has the stock thicker than the blade, for convenience of being able to set the stock against an edge when squaring over, or down. When the two are of the same thickness, the instrument can only be properly used as a set square, that is, be laid upon one outside edge, testing by the other outside edge. Or the inner edges can be used for checking work already brought into an approximately square relation, but not for marking lines by from an edge laid across a face.

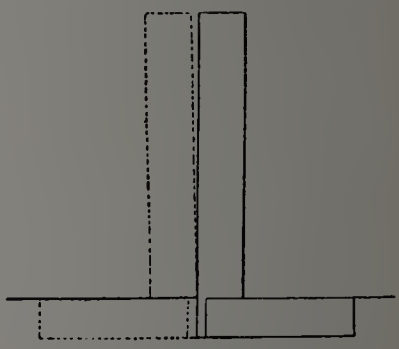


Fig. 295.

In checking edges it is very essential that the blade of the square be kept perpendicular with the edge being tested. If thrown over, any slight lack of truth in the blade itself will falsify the test.

Squares can be easily tested by laying one edge—that of the stock—against a true base, marking a line by the edge of the blade and then turning the square right round, and testing the same edge

by the same line (Fig. 295). Any departure from a true right angle in the square will then be apparent, being just doubled.

The usual method of making try squares is, after having prepared the blade, and the stock, just as separate straight-edges would be prepared, to cut a saw kerf in the stock, finishing the cut with a narrow file to admit the blade. Having then set the blade square, holes are drilled for rivets, and one rivet after another is inserted, checking the truth of the blade, and making any necessary corrections as each rivet is closed.

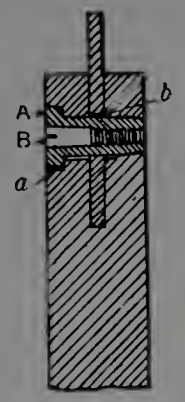


Fig. 296.

There is a disadvantage in this old practice, inasmuch as any future corrections of the stock and blade have to be done with the parts fast together. Corrections become necessary at intervals, because the inner face of the stock and the inner blade edge wear more next the inner angles, than near the outer portions. Moreover, squares become damaged by falling on the ground, or by articles dropping on them. It is convenient, then, to be able to take the blade and stock apart for correction. This can be done when the fittings are those shown in Figs. 296 to 301.

Fig. 296 is a section through a square in which the blade fits into a slot. But instead of using rivets, which do not permit of

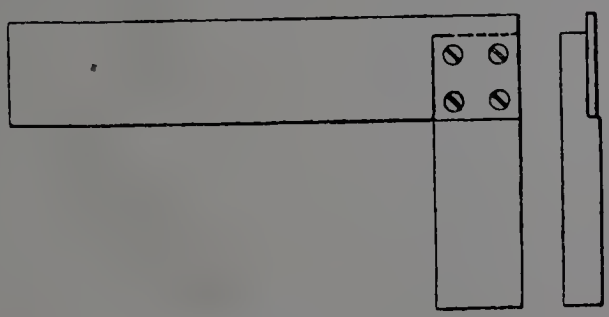


Fig. 297.

after-adjustment, a special form of screw A is employed. It is split through a portion of its length, and expanded by the tapering screw B inserted in its centre. The act of tightening the screw pulls the blade against the shoulder of the stock by the very familiar device, used in cottared work, of leaving slight clearances at *a* and *b*.

The form of square which has some advantages in manufacture

over the old central blade type is shown in Fig. 297, in which the blade fits into a recess cut in one face of the stock. Various methods of fastening these are shown in subsequent figures. Fig.

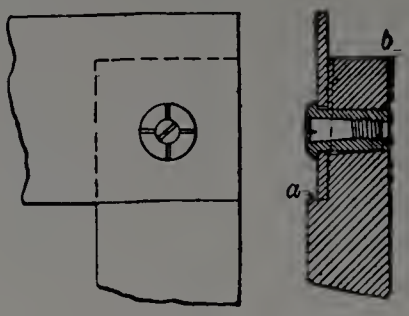


Fig. 298.

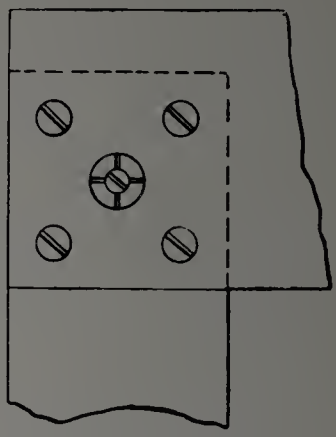


Fig. 299.

298 shows the screw and the split expanding busk in section, and the dotted lines are introduced to show the effect of tightening the screw, in cottar fashion, the pressure along the edge *a* tending to force the stock over at *b*. The amount of spring is extremely minute, but sufficient to provide an elastic force which keeps the blade well up to its shoulder.

Fig. 299 shows the method employed in large squares, in which, in addition to the special screw in the centre, four common screws are put in near the corners to reinforce the work of the central one.

Fig. 300.

Fig. 301.

Figs. 300 and 301 illustrate methods of fitting with common tapering screws, not split, but which draw the blade up as already mentioned. These are a B. & S. device.

Fig. 302 shows another type of square, the Starrett, in which the stock and blade can not only be taken apart, but can also be adjusted lengthwise, which is a very convenient adjustment when squaring work in which a shoulder would interfere with a blade of ordinary length. The blade has a groove, and the stock a special

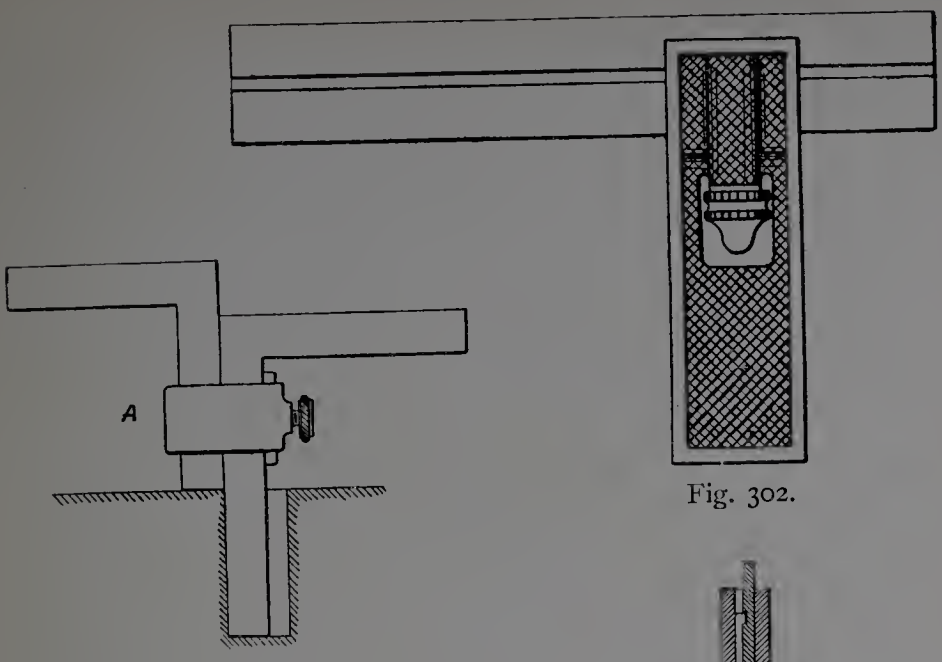
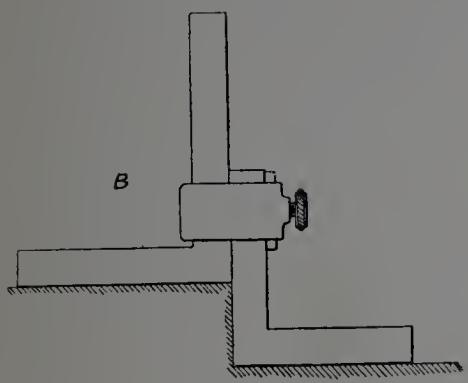


Fig. 302.

Fig. 303.



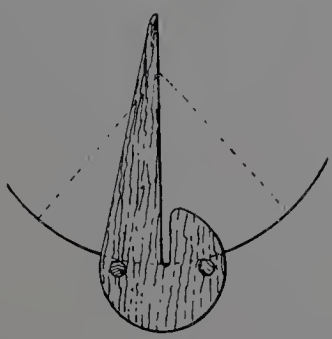


Fig. 305.

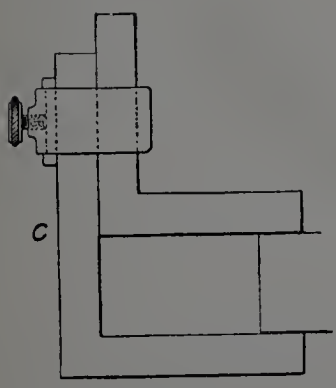


Fig. 304.

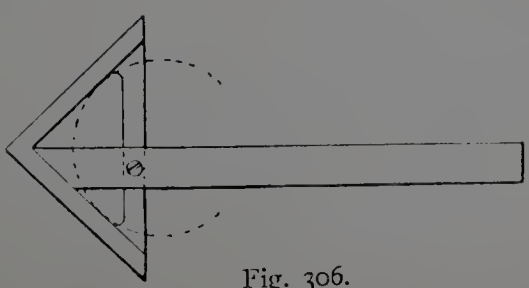


Fig. 306.

clamping bolt and nut, with milled head, which permits of shortening or lengthening the amount of projection of the blade at either end out from the stock. See the section, Fig. 303.

In many instances the blades of squares are divided into inches and parts, which are convenient for measuring depths or lengths simultaneously with squaring over or up.

Fig. 304, A, B, and C, shows a home-made combination square, which is formed by the attachment of two flat squares with a strap, provided with a milled-headed screw, pressing upon a washer strip. There are many possible ways of clamping the two squares together, three only of which are shown. A depth gauge is produced when the two are back to back, as in A; held in the same manner, but turned upside down, a shoulder gauge is formed B, while if one square is placed within the other, a caliper, or thickness gauge is the result C. There are many other combinations of this useful tool, which can easily be imagined.

The centre squares are a very useful alternative to dividers, for finding the centres of circles. The patternmaker, and woodworker employs that in Fig. 305, consisting of a piece of wood of suitable form, provided with two pegs, which coerce the square around the edge of the disc being centred. Short lines are scribed across the vicinity of the centre, and when the square has been shifted around three or more times, the intersection of the lines provides the centre. The same class of tool, but in metal, is shown in Fig. 306, where instead of the pegs, the head itself forms an angle, the sides of which make contact with the circle, while the straight-edge screwed to the head, cuts across the centre. Another form, made for attachment to a splined rule, of the type shown in Fig. 302, is shown in Fig. 307, and it transforms the rule into a centre square for the time being.

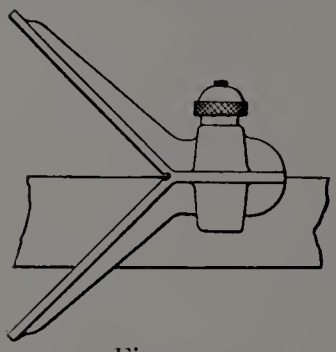


Fig. 307.

Set squares are not used so much by machinists, as in the drawing office, and pattern shop, and woodworking trades, the try square being as often as not used as a set square; but they form a portion of the equipment of the machinist and fitter.

To the proper utility of the set squares, the taking of fixed

angles is added, as 30°, and 60°, or 45°. These angles are wanted so frequently that time is saved by having them combined with set squares. For other angles, the bevel, or bevel square, is employed. The function of this lies, however, more in the testing of angles that are already brought into approximate relations, than in the setting out of angles. Or they are used for taking the angles from a protractor, and laying them out on the work.

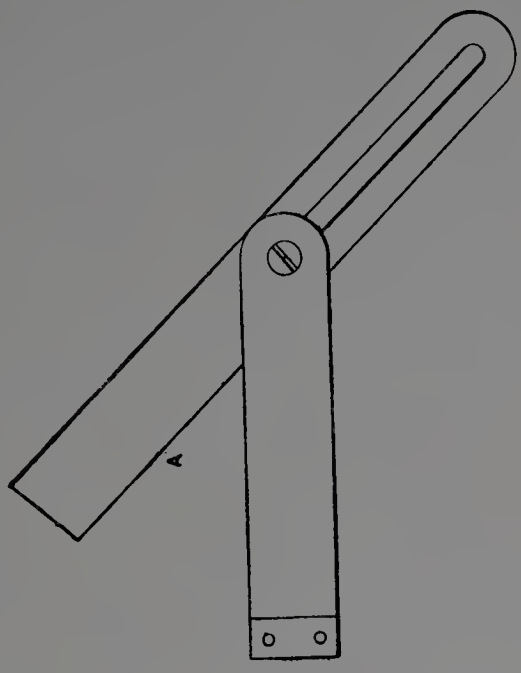


Fig. 308.

Sometimes one sees common rules divided into angles at the knuckle joint. These should never be employed excepting for the roughest class of outdoor timber work, for which they are handy. The principle is bad, to use a very small radius of graduations in order to obtain angles for lines several inches or feet in length, and it cannot be done accurately in practice, however great the care taken in setting.

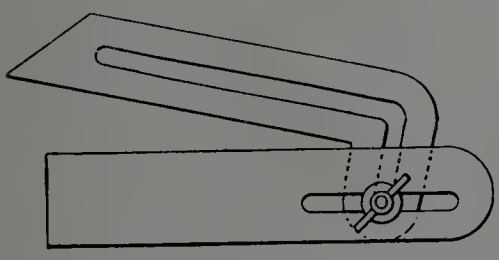


Fig. 309.

Squares, bevels, and straight-edges render themselves adaptable to many useful combinations. Bevels are made in various forms, both simple, and in combination with protractors. The common bevel in which the blade is straight and the slot down the centre, lacks range, because the edge A, Fig. 308, comes out a considerable distance down the stock. To avoid this is the reason of the design in Fig. 309, in which the blade has an offset at one end, so permitting the taking of the most acute angle right from the end of the

blade. Besides this, the open slot which occurs in the ordinary stock is filled in on the side next the blade in Fig. 309. The advantage of this is that thin templets can be laid on the stock directly beneath the blade, which cannot be done when the stock is pierced right through.

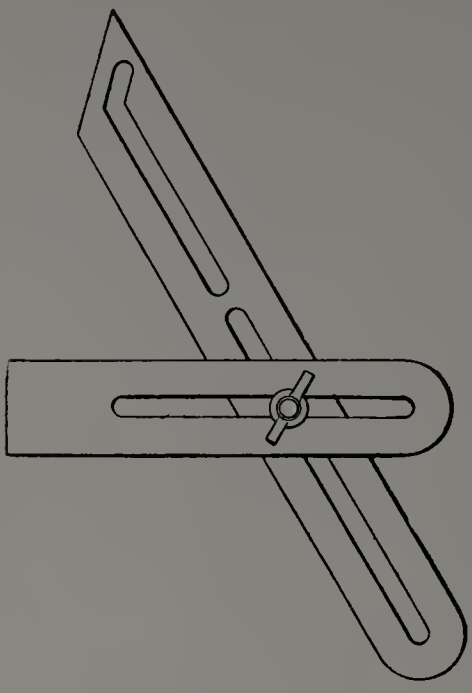


Fig. 310.

In one form of bevel, Fig. 310, the stock is slotted as well as the blade, so permitting of a wider range of adjustment than the common form does.

The familiar combination bevel, Fig. 311, can be used in the same way as the ordinary form, or double by the addition of the auxiliary blade A. The blades can be clamped at any angle by the knurled nuts, and the three blades used in an infinity of combination for turning gear-wheel blanks, planing vees, &c. Its range of utility is increased by grinding the ends of the blades to definite angles, so fulfilling the functions of set squares. In one design the slots are pierced through two blades; in the other, shown in Fig. 311, one blade only is slotted, the others being vee grooved and having bolts which fit these grooves.

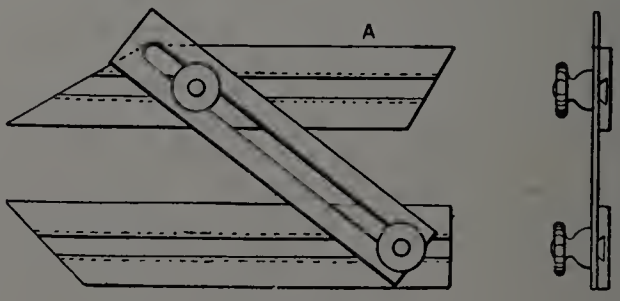


Fig. 311.

Protractors, or bevel protractors, are tools in which the angles are measured, or set off exactly in degrees. There are many forms of these. Besides these, there are combination tools in which

rule, square, mitre, bevel, and protractor are embodied. In the common brass protractor supplied with mathematical instruments, the base is very short, and leads to error in setting—error that becomes magnified. Though suitable for small angles, it should not be employed for large drawings. In setting out the sections of large bevel gears, for instance, an error of a degree or two might easily be made from the protractor to the major diameters, and this would produce a very gross error in results. The aim should be, therefore, as in other departments of practice, to have a basis as large as, or larger than, the work to be laid out, so that error shall be minimised instead of magnified.

In the Brown & Sharpe protractor, Figs. 312 and 313, the blade A forms an extension of a circular portion fitting by vee'd

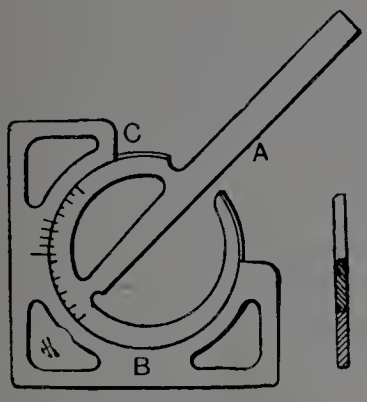


Fig. 312.

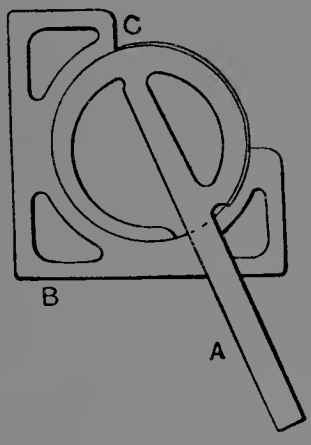


Fig. 313.

edges in a frame B, of the same thickness. The circular form permits of the blade being prolonged inwards past the centre of the protractor, so that a line can be drawn, which cannot be drawn when using the ordinary form. The divisions go past 90°, and in addition there is a vernier on the frame which gives readings to 5′, or one-twelfth of a degree—another refinement on ordinary protractors. When the back of the blade is brought back against the edge of the frame, as at C, the instrument stands at zero. The square outline of the frame allows it to be laid against a set, or try square readily, and so often saves trouble. The second figure illustrates the method of insertion of the central part in the frame, into which it is placed in the manner shown, a slight amount of spring being possible.

The Brown & Sharpe universal protractor, Fig. 314, has its stock extended towards one side, a circular dial A is divided round the entire circle, and the divisions are protected by having them below the surface at C. The dial turns on a hardened central stud of large diameter. The line of angle is marked by a straight-edge B, which is tongued similarly to some of the firm's rules, so permitting it to be slid longitudinally in its seating, and clamped independently of the dial.

The value of very minute degrees of angle comes in when turning wheel blanks, and when turning or boring tapers. These almost invariably include minutes of angle as well as degrees, and an exact setting ensures true work. Even though work is first

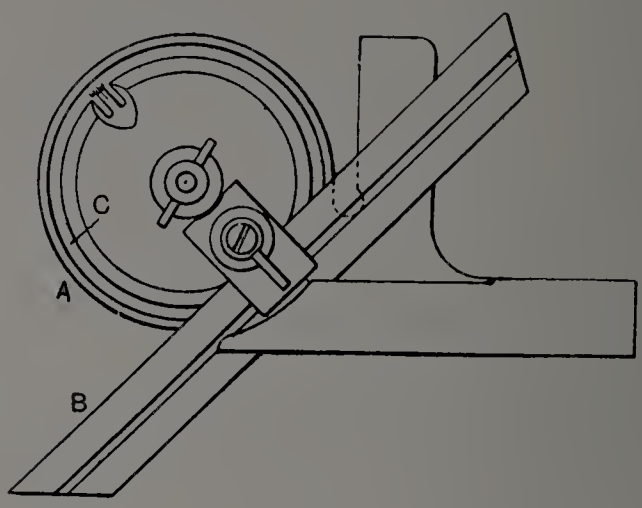


Fig. 314.

struck out correctly, it is convenient to check it with a finely graduated protractor.

For the largest work of a shop the scale of chords is better than the small protractors. Measurement can be taken from a sector. But a better plan is to construct a scale either in metal or in wood. It can be made of any suitable dimensions by the workman himself, and accurate, in the following way :—

Strike a quadrant of a circle, Fig. 315, and divide it into 90°. The radius may be 1, 2, or 3 ft. at pleasure, according to the requirements. Then take a straight-edge of boxwood, or of metal, gauge two parallel lines along it about $\frac{1}{8}$ in. apart, Fig. 316, and mark off between these the exact length of the chord of the

quadrant; that is, the length of the straight line or shortest distance between the extremes of the 90°. Now, one by one take off carefully, first with compasses, and then with trammels as the distances increase, the chord lengths corresponding with the divisions into degrees, from the quadrant, and transfer them to the line of chords on the straight-edge, always working from one end. For the first 15° or 20° there will be no appreciable difference between the lengths of the arcs and of the chords, but after that the chord distances will begin to shorten until the 90° is reached. Square all these divisions carefully across between the two lines gauged on the scale, and these will form a permanent instrument for setting out angles by. To use it, an arc must be struck with a radius measured from zero to 60° on the line of chords, on which the angle required will be set out.

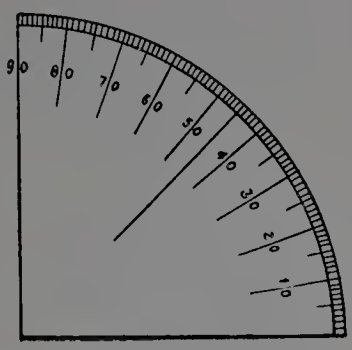


Fig. 315.

Spirit levels are used by machinists and fitters for levelling and plumbing work on machines and in work in course of erection. The levels with wooden stocks are being displaced to some extent by those of metal, which are less liable either to become worn on the bottom, or to warp. Levels are also fitted to squares, to be used when squaring up work on machines, and in place. They are also fitted with provisions for adjustment, and correction. There was never so great a wealth of these instruments, in numerous types and sizes as there is at present.

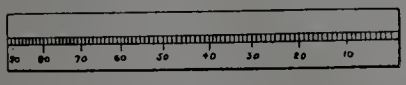


Fig. 316.

Levels with wooden stocks are not the best for engineers' use, though suitable enough for the woodworking, and building trades. They are not so suitable for moulders, either, as the metal ones, because the sand soon roughens up the bottom, and impairs their accuracy. It is to delay this wear that the bottoms of the wooden ones are frequently tipped with brass angle pieces, as in Fig. 317.

The evil of wear is a serious one in levels, so that after a moderate amount of service, it becomes necessary to turn the level end for end, to correct and average the observations. The

stock being so short, hastens the wear. For this reason levels are sometimes screwed on the top of a long parallel strip, with the ends chamfered off (Fig. 318). A usual practice also is to lay the level on the top edge of a long parallel straight-edge, but this is

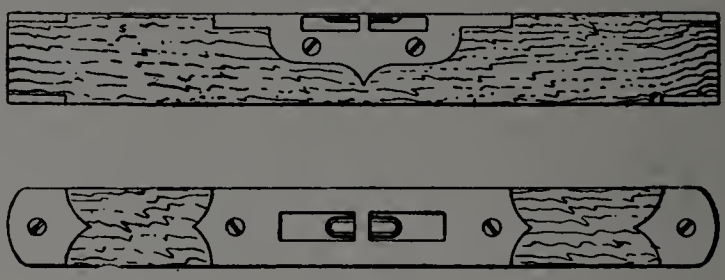


Fig. 317.

done in order to average the inequalities of large surfaces which are not perfectly true.

Another point is that in levels, generally, one must be in a

Fig. 318.

position to look down upon them in order to see the bubble. To avoid this, is the reason why what are termed, side views are provided in some levels, so that the bubble can be seen with the

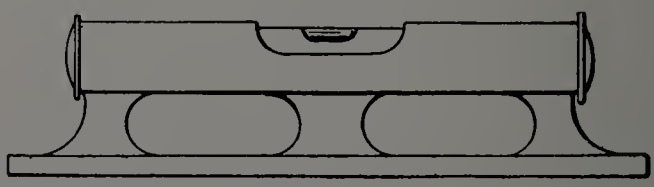


Fig. 319.

eyes at the same height, or even a little below the level, as in Fig. 319.

In one form of level, instead of having a side sight to the glass in the top of the instrument, a separate glass is inserted in the body of the stock, and protected by brass discs.

Levels for the use of machinists should preferably be of metal. A useful kind is that in which the glass tube is enclosed in a tube

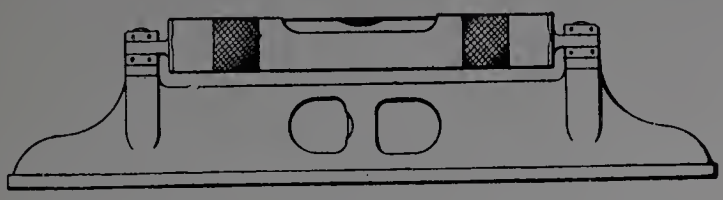


Fig. 320.

of brass (Fig. 319). The tube protects the glass, and the foot does not wear sensibly for a long period. Another suitable form for machinists is made after the girder section, with top and bottom flanges connected with ends, and connecting curves or bars, in place of a solid web. These, having two flanges, are readily used as plumb levels, and they generally have two tubes for plumbing, one near each end. Either flanged face, and either end, can then be used.

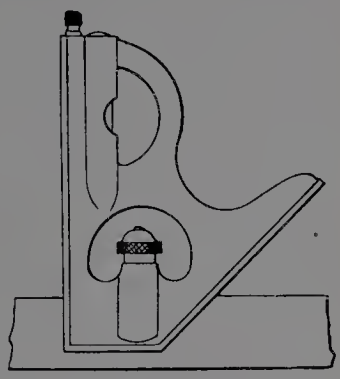


Fig. 321.

Many levels have a longitudinal vee groove along the base, which allows them to be used on round shafts, or tubes, without affecting their utility for flat surfaces.

Fig. 322.

These levels are rigid, that is, they have no means of adjustment for the tube to compensate for wear. Another class made by Starrett's (Fig. 320), have such means of adjustment. The ends of the brass tube are prolonged into flat lugs, which fit over a couple of screws let into the main base. A nut above, and one below provide a means of raising or lowering each end of the tube, and locking the same rigidly. The tube casing also can be turned round to protect the glass when not in use, being knurled for the fingers.

Fig. 321 shows a combination form of head, fitting on a splined rule (of the type in Fig. 302), which comprises a spirit level, a square, and a bevel, having an angle of 45°.

The plumb bob is allied to the levels, inasmuch as it determines the vertical truth of objects. Used as a bob simply,

suspended from a thin cord, it determines the perpendicular relations of centres. When employed against a face desired to be vertical, it is combined with a parallel straight-edge, the bob being contained in a hole cut through the straight-edge near the bottom. It is then termed a plumb rule. The general objection to the common plumb, of brass or lead, is that it sways a long time before coming to rest, which is the reason why the workman steadies it with his fingers. To avoid this trouble the bob shown in Fig. 322, is designed. It is a long hollow rod, small in proportion to length, and is filled with mercury, which makes it unusually heavy. The small diameter allows it to be used close to walls, and upright faces. A silk line is attached to the top cap, for suspension.

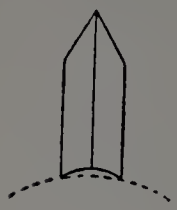


Fig. 323.

A useful tool is shown in Fig. 323, employed in connection with ratchet drills, on cylindrical surfaces, as those of boilers. The tool, made of sheet metal, is stood upright on the work, and when the centre of the drill, or the ratchet body coincides with the point of the instrument, it is square with the job.

CHAPTER XXI.

Surface Gauges, or Scribing Blocks.

The Work of Lining-out—Preliminary Checking of Leading Dimensions—Centre Lines—Cardinal Dimensions—The Basis of a Level Table—Packing up—Details—Scribing Block—Its Work—Illustrations of its Use—Differences between Good and Bad Forms—Various Kinds—Refinements Described—Scribers.

THE general problem in the work of lining-out is that of scribing any lines on surfaces in any position, and also of ensuring absolute relations between lines on the same, or on different surfaces, for which there is often no means of direct checking, as there is, for example, on a level plane, or on a drawing. Besides this, the truth, approximate or exact—always using the words in their shop sense—of horizontal, or vertical faces is often included.

A large section of engineers' work—the largest in the average shop—is done by lining out, and working by these lines. All massive work is so treated, and all that of medium dimensions in which the quantity turned out is not sufficient to pay for templets, jigs, and gauges. It is one of the most important sections of practice. Usually the men who do it—the markers-out—perform no other duties, though in numerous instances a man has to line out his own work, and then machine, and fit it up. The tendency, however, for many years has been to throw this particular department more and more into the hands of the marker-out, who thereby acquires deftness and experience which shorten the process.

In the work of lining off we meet with a very different set of conditions from those which exist in working by gauge. The difference is that between laying out dimensions to be worked by, and in checking dimensions already tooled. But after work is lined out and tooled, gauges are often employed to check it by, or the rule and calipers may be used for the purpose, so

that there is an overlapping of these broad methods. Again, the templet is a half-way device, used instead of lining out, or as supplementary thereto, to save the trouble of marking out a number of lines with rule and compass, &c.

In almost all cases we may say that in practice the lines marked out are never worked by, in the sense of trusting to them absolutely without further check, in any but the roughest productions. The turner and machinist check results with movable calipers, and refer these to the rule; or measure with the rule direct, thus coming back to rule measurement as the last check on work previously marked by it. This represents common, or average practice now. Gauges and templets are also made from the rule, and used to check the results of tooling; but these again in the general system depend for their accuracy on the rule, and the ideas of the workman with regard to the limits of accuracy necessary or permissible, working as exact as vision is able to detect, or full, or bare, as seems necessary for tight, and easy fits.

The instruments of measurement used for lining-out are rules, compasses, dividers and trammels, scribers, scribing blocks, or surface gauges, and calipers; assisted by squares, protractors, straight-edges, and centre punches.

Before the marker-out can set out all the lines by which machining is to be done, it is necessary to check leading dimensions roughly. The reason for this is, the inaccuracy present in cast, and forged work, which has to be averaged by a give-and-take process, by allowing more in some parts, and less in others for tooling than the regular amount. This is not very easy to do where allowances are cut fine on intricate work. Several centres, and over-all distances may then have to be checked, as well as the relations of faces or the axes of holes. Hand-made forgings and jobbing castings of large dimensions are the most awkward to average, while drop forgings and plate-moulded castings are the least inaccurate. In fact, in these the work of lining-out is generally saved, and templets substituted, because the forgings and castings show practically no differences in dimensions.

In the cylinder, Fig. 324, the dimensions which have to be mutually checked are seven in number. There are the foot A, flange B, facing C, and flange D, which have to stand either square with each other or parallel. But when these are averaged right, the bore E may be found too much to one side or another, making

the distance *a* or *b* from the centre incorrect. Or the flanges F, F may be out of square with the bore, and with the foot A, or flange B. The question is far less often that of whether any single section will hold up to size, as whether all will hold up, when standing in their proper relations, square, or it may be at a bevel, and to correct centres. Hence the reason why careful averaging by the liner-out is necessary. It may be thought that the remedy for this would be to give plenty of allowance for tooling. There are limits, however, to this, though it is done to a reasonable extent. It is obvious that the finer allowances are cut for machining, the greater is the care which has to be exercised in the production of pieces, whether castings or forgings, of reasonably uniform shape and dimensions.

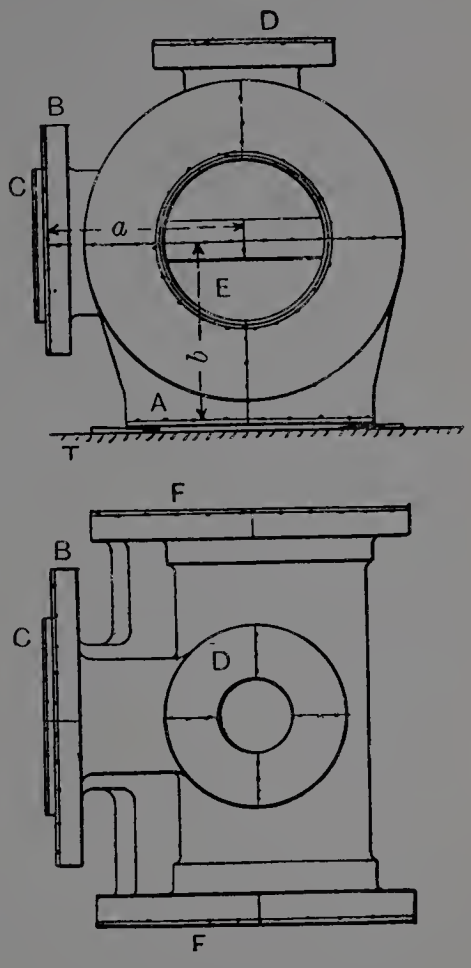


Fig. 324.

Or, taking the common illustration in Fig. 325, such a forging when made on the anvil is very unlikely to be even approximately exact. To set it out, the marker-off has to start from centre lines *a*, *b*, ran round on each face, the planes of which would cut each other at exact right angles. Then lines for the three boss centres have to be squared up on all faces. Probably the boss centres will not come as they should, and two or three attempts may have to be made to locate such centres as will permit of each boss tooling up to its proper diameter. The faces of the end bosses may not measure alike from the faces of the central boss, and then the centre line *b* may have to be shifted to average these. Or the forging may even have to be set afresh by the smith.

In most work there are cardinal dimensions, and secondary or

less important ones. The intelligent liner-out goes for the first ones, and takes little account of the second. Another man makes no such distinction, but treats all alike. The cardinal dimensions in the foregoing figures are those that have been mentioned. The thickness of flanges in Fig. 324, and those of the webs in

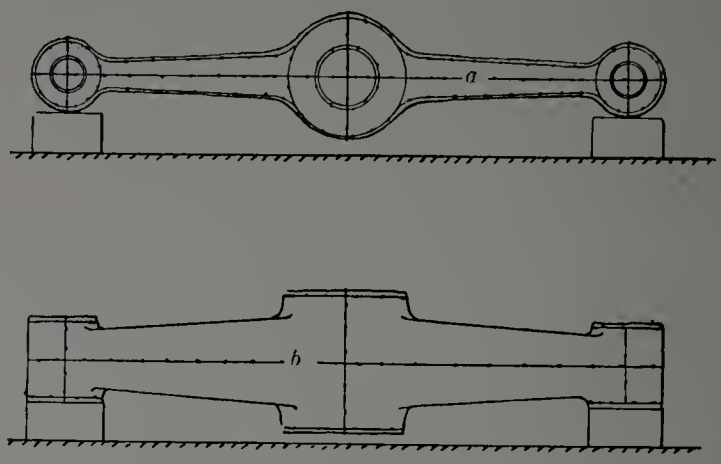


Fig. 325.

Fig. 325, have to be accommodated to the others—within reason, of course, because too great thinning down of a flange or web would condemn the piece as a waster in a shop where regard is had to reputation.

In lining off work, the basis of operations is the face of the iron marking-off table, the face and edges of which are planed truly and square. From its face the surface gauges are worked, and squares are set up. The first thing to do, therefore, is to fix up the casting or forging on the table in such a way that it cannot rock, and in such a position that the first set or sets of lines can be scribed or squared from the table. Frequently, when a suitable face exists, a cut is taken over that face first, and by that the work is laid upon the table. Such would often be done with the face A in Fig. 324, though a rough preliminary checking over of the casting would be desirable. If the face is utilised in the rough, as in Fig. 324, it has to be packed up on wedges, as shown, or on blocks as in Fig. 325, until an average level is obtained, and the face to be tooled is scribed round. Sets of parallel blocks of

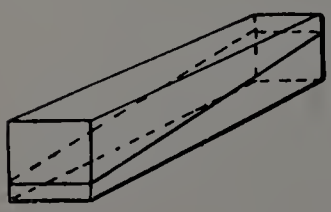


Fig. 326.

various thicknesses are part of the equipment of the marking-off table, being solid blocks planed on all faces, or I sections. Wedge blocks (Fig. 326) are also used. For circular work the vee blocks are employed, and these are fixed (Fig. 327), or adjustable for height (Fig. 328), or one block contains several vees as in Fig. 329. By these devices artificial bases are obtained for pieces of work of all shapes above the level of the table, whence the scribing blocks, squares, and other instruments of measurement and checking are used.

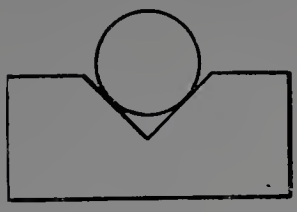


Fig. 327.

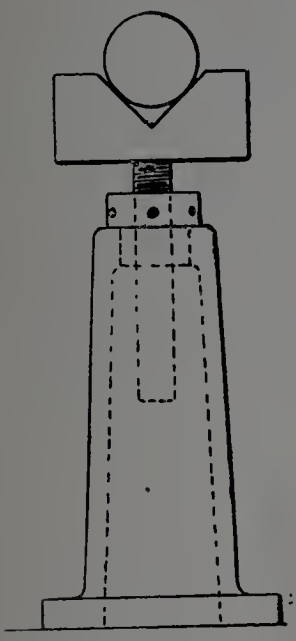


Fig. 328.

An important point is that all the lining-out possible should be done at one setting, to save time, and to get on all the lines available before changing the position of the work on the table, a precaution which conduces to accuracy. Many pieces of work, of course, are lined out entirely at one setting.

Every line struck out in this way is put on with a pointed tool of some kind—scriber, compass, &c.,—and is therefore liable to error. And every dimension is taken from a rule, and is liable to error in the transference. To lessen risk of the first, the lines are drawn very fine, on a surface whitened with chalk, or with a wash of whitening. As these lines would easily become obliterated in subsequent handling and in contact with the oil about the machines, their course is indicated with fine centre punch pops (Figs. 324 and 325). Frequently, too, in turned and bored work a second line is struck concentric with the working line, to remain as a "witness" after the work is machined that it has been tooled truly, as in Fig. 324.

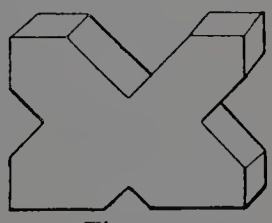


Fig. 329.

Though the scribing block is mainly a marking instrument, yet it is, as its synonym implies, a "surface" gauge. Its turned-

down point is employed in checking or testing the truth of a horizontal surface by contact therewith, the sense of touch coming into play. This is an extremely handy means of levelling up, in place of a direct measurement by the rule, besides which there are numerous instances in which the latter would not be available, as in circular work, the highest surface of which would not be accessible by the rule. The straight point both marks and checks lines on vertical or sloping faces. The means of effecting minute adjustments for height are sometimes simple and crude, in others very fine and precise. In most the pillar is fixed in a base; in some it is hinged. The base must be massive, in order to ensure the steadiness of the gauge. Its bottom must be true: it is generally hollowed out underneath to bear around annular edges only. The fittings of the scriber and its block

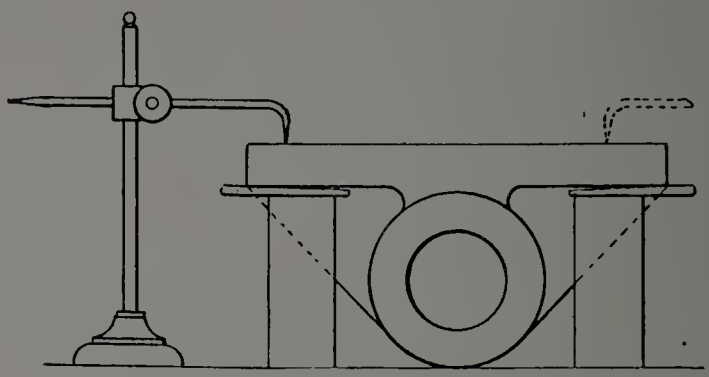


Fig. 330.

must be very good. Some gauges are made for sliding on a level surface only, others are vee'd, and others are vee'd both on the end and bottom, to be used either way.

The work of the scribing block is of a manifold character, both in regard to the actual work of marking out and as a preliminary thereto. Say we want to level a casting or forging before lining it out for tooling (Fig. 330). The instrument is then used as a surface gauge first, the turned-down point indicating the position of the face in relation to the face of the table, whence the lines are to be scribed presently. Blocking and wedges afford the means whereby the casting is levelled up to the required position indicated by the gauge.

This, in passing, is a different thing from using a spirit level, although levelling is the object in view in both cases. But using

a gauge, the basis, whether the marking-off table or machine bed, need not be perfectly horizontal, while with a spirit level it must be. Hence the surface gauge is often a very much more convenient tool to employ than the spirit level.

The surface gauge reversed is used for the levelling of bottom faces. Suppose that the tooling of a piece of work has to be

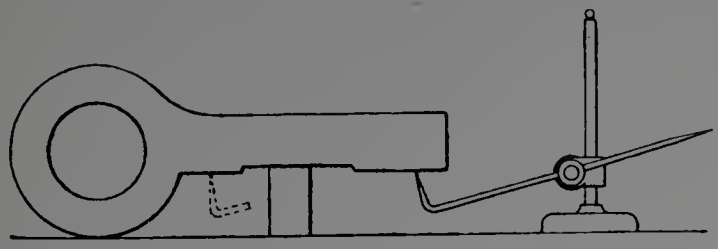


Fig. 331.

done in relation to a face already tooled, or in any case taken as one to commence from, and that face cannot be laid directly upon the table because a boss or lug or other projection comes in the way: then the piece of work, suitably packed up, is levelled by bringing the turned-up point of the scriber against the bottom face (Fig. 331), and so making corrective adjustments.

The scribing block is employed largely for transferring dimen-

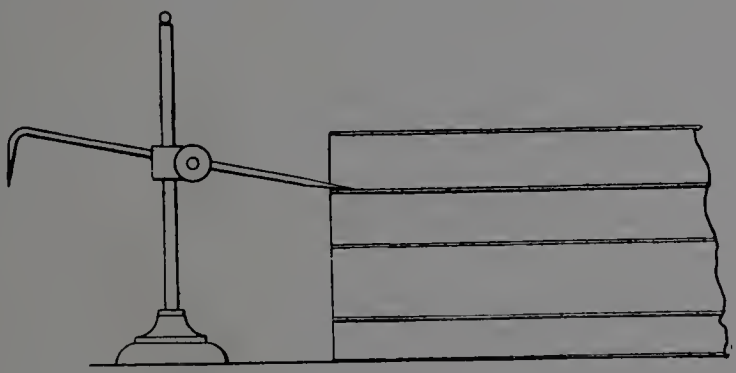


Fig. 332.

sions, as well as for marking centre lines and edge lines. When the vertical face of a piece of work is a plane, it is easy, of course, to lay off dimensions one above another directly with compasses or dividers (Fig. 332). But when the faces to be marked stand out at different levels, this is not practicable. Of course it can be done after a fashion by using a compass or trammel with an extension leg, but that is not accurate enough. The proper course,

then, is to set out the dimensions on a block (Fig. 333, A), stand that upright, and transfer the lines directly from that to the faces of the work. Or the rule is stood on end against a square block to keep it upright, and so used. Several firms now make height-measuring appliances specially for the marking-off table for this particular purpose. In one form a divided stem is fixed permanently in a circular base; in another a common steel rule is clamped in a vertical position on a base (Fig. 334).

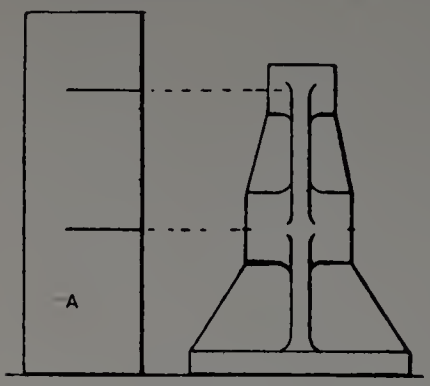


Fig. 333.

Another use of the scribing block is the locating of centres of circular work, either shafts or discs. The first is rotated in vee blocks; the latter on edge on the table into fresh positions, in each of which a short line is scribed in a position approximating to the centre, and the mean of four to half-a-dozen such lines taken as the centre.

These are the leading functions of the surface gauge or scribing block, but many forms are designed for a wider range of operations.

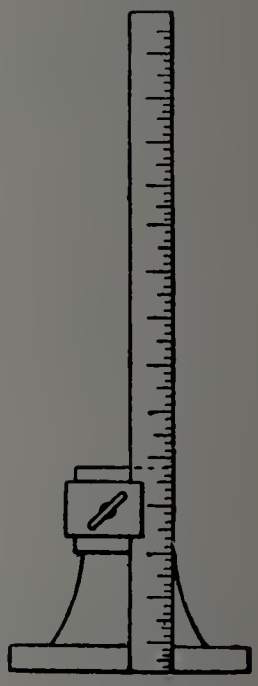


Fig. 334.

The fault which all the home-made blocks have is not that they are badly fitted—for they are generally made very neatly as a work of love—but that they have no fine adjustments. When the pinching screw is slackened, there is nothing but the fingers to prevent the scriber from dropping from its position. Consequently, when fine adjustments are being effected, the screw is partly released, and the point tapped with rule, or scriber, or centre punch, much as caliper legs are tapped with the same object in view. And this tapping is a very uncertain and clumsy process. The best manufactured surface gauges have a spring friction enclosed in the boss holding the scriber, by means of which both the sliding sleeve and the clamp or clasp which

grips the scriber are just retained in position, though the screw is loosened. A fine adjustment for height is effected by a knurled disc, which on being turned slowly revolves the clasp in which the scriber is held, so that it can be set to any exact height. Fig. 335 illustrates a Brown & Sharpe gauge of this kind.

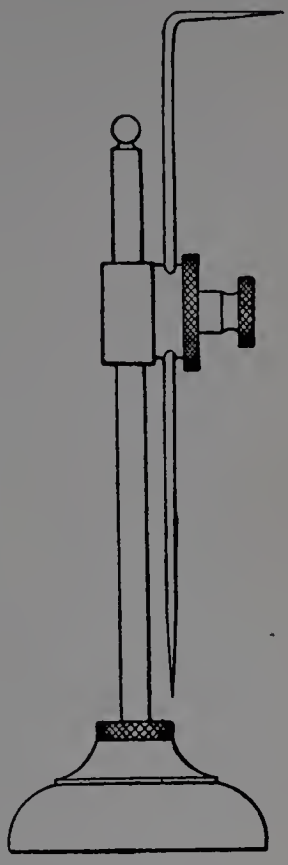


Fig. 335.

In another type (Fig. 336) the height is adjusted finely by a lever and screw attached to a socket, into which the post is stepped. The point of the screw rests on the extension of the base block, and by turning it the fine adjustment of the point is effected.

In a Starrett gauge (Fig. 337) the height is adjusted micrometrically by a nut on the base, reading to thousandths of an inch. An extension piece is fitted (Fig. 338) to increase the height of the stem by 6 in. In another, by the Stevens Arms and Tool Company (Fig. 339), fine adjustment is effected by turning a thumb-screw at the top of the post to graduations, each of which gives an adjustment of a thousandth. The scriber is used as a depth gauge, passing perpendicularly through the hole shown in the base. The knob at the top is to prevent the knurled nut from being run right off, and lost.

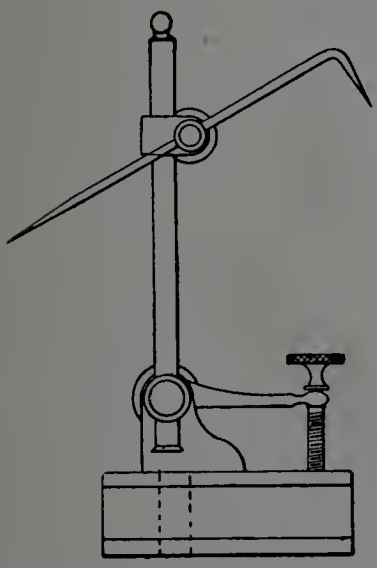


Fig. 336.

Fig. 340 is a Starrett surface gauge in which the base is cut away in one part to permit of the use of the tool as a depth gauge. Fine adjustment is effected by the knurled nut in the base. There is also a spiral spring in the base to take up backlash.

Among other refinements, the Billings gauge (Fig. 341) should

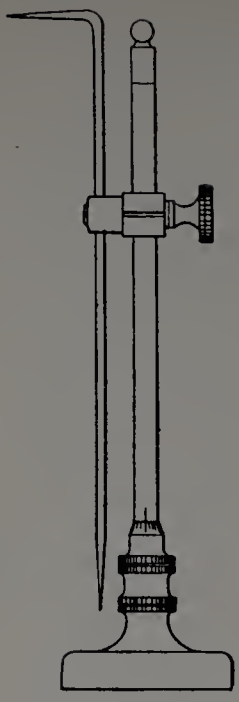


Fig. 337.

Fig. 338.

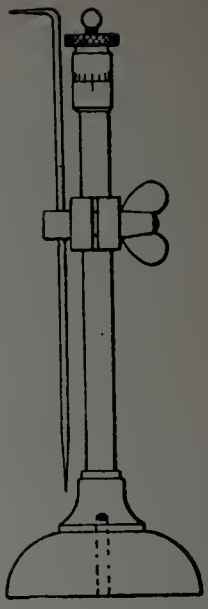


Fig. 339.

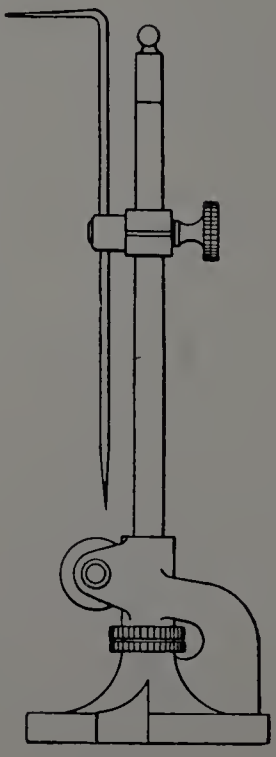


Fig. 340.

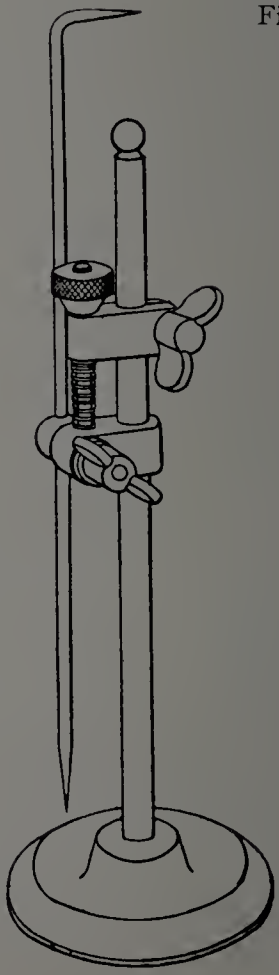


Fig. 341.

be mentioned, in which the scriber is steadied by two blocks or lugs—the one in which it is carried and to which it is clamped, and another higher up connected to it with a screw, and sliding on the post or standard. The upper one is clamped to the post. In another surface gauge a spirit level is fitted in the base to test a surface by.

Fig. 342 represents a gauge by the Massachusetts Tool Company, in which fine adjustment is by the milled-headed screw in the base, while the spring below takes up backlash. The front end of the base is cut away at the centre to permit the use of the scriber as a depth gauge. These are nice refinements which are not present in the shop-made articles.

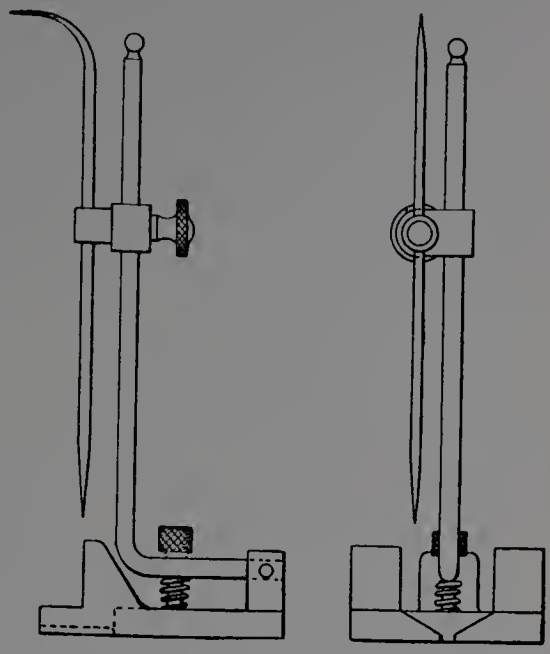


Fig. 342.

Many gauges are made with a vee'd base to permit them to be slid along shafts and bars for the lining-out of work on those shafts, which would otherwise be inaccessible. These occur in home-made, and in manufactured forms, but the latter are gene-

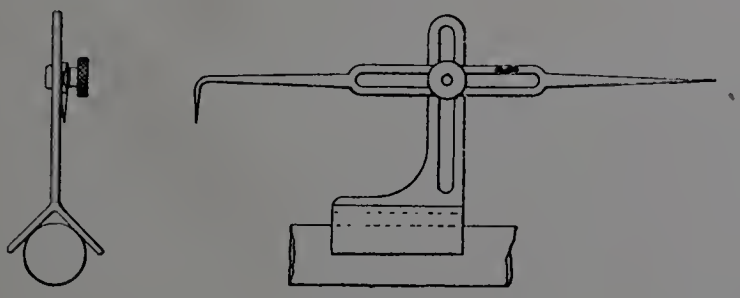


Fig. 343.

rally found in combination types used for flat and circular surfaces. Fig. 343 shows the home-made article. But more handy dwarf scribing blocks are manufactured, provided with a vee on the bottom face or on the end, to permit them to be used on circular

rods, shafts, or boring bars. In one form, hardened pins stand out from one face to allow the gauge to be slid along a straight or curved edge, or in a groove such as those on planing and milling machine tables, &c.

Manufactured surface gauges may be divided into two very broad types, the common forms just noticed, and the universal. The latter are comparatively recent. Their broad features, modified by different manufacturers, are these, Fig. 344, representing a typical Brown & Sharpe form :—

The gauge is supported and hinged at one end of a rather heavy rectangular base. The post fits into a boss which swivels

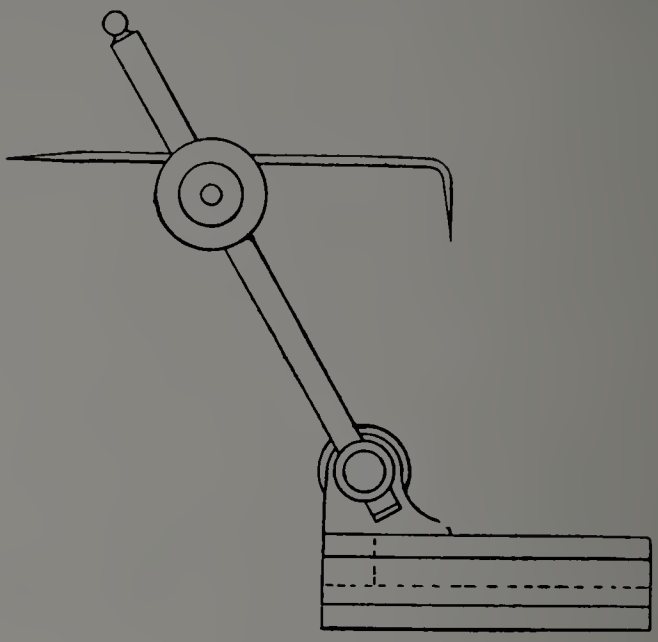


Fig. 344.

in a vertical plane in a lug standing up on the base, so that it, with its scriber, can be set in any position from vertical to horizontal. This permits the use of the scriber in any position, even below the base, for marking lines or gauging a depth. The post with the scriber is held in any position by friction springs during the making of exact adjustments, when the clamping nut is loosened, and remains so until the adjustments are effected, when a slight turn of the nut secures the parts in the required position.

To render these instruments still further adaptable, the base is frequently grooved to fit circular work. One end of the block as well is also often grooved similarly to extend the range of its

utility. Another improvement sometimes included is the fitting, just now alluded to, of two pins through the block near the rear of the base, as in some of the Starrett tools. When these are pushed down, the base can be slid along the edge of a surface plate, or the edge of a slot in the bed of a planing machine when straight or parallel lines have to be marked on the horizontal surface of a piece of work.

A good many operations can be performed with a surface gauge of this kind that are beyond the range of the rigid pillar type with an ungrooved base. The pins permit it to be slid along straight edges for marking parallel lines on horizontal faces, or round curved edges for concentric curves. A grooving at the front edge allows the post to be passed down through that groove, so that the scriber will mark lines parallel with the base. Lines can be marked round cylindrical work, while the bottom groove rests on a central shaft or mandrel. Lines can be marked on wheels, discs, and circular work, the centre of which is inaccessible by reason of the presence of shafts and spindles, the gauge being set around these. In one universal instrument—the "Carr"—the base has two horns standing up at a right angle, so permitting the block to be slid along a true edge, and fulfilling the function of the pins just noted. The post is pivoted to fall between these lugs when required to work in a horizontal position. It can also be turned down to be used underneath a piece of work or along a bottom edge. There is a vee milled on one side of the upper surface which permits the instrument to be used around the edge of a face-plate, or on the end of a shaft. This gauge has a fine adjustment of $\frac{1}{4}$ to $\frac{3}{8}$ in. for the point of the scriber, operated by an eccentric washer at the base of the post.

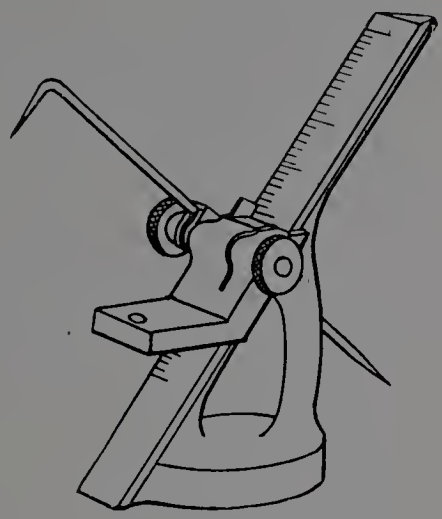


Fig. 345.

In another gauge the post is enclosed in the middle of a block, in which it is permitted a movement of three-fourths of a circle. A large vee groove at one end permits the instrument

to be used round the edges of curved work, either face or cylindrical. A tongue on one side allows the gauge to be slid along the edges, or in the grooves of planer-tables, &c. In another universal gauge a still further range is included—that of trammel points. There is another very useful combination tool, the Stafford & Whipple planer and surface gauge (Fig. 345), designed specially for use on the planer. A diagonal rule on a broad base carries an adjustable sliding block, which holds the scriber point, aud a horizontal test foot. The latter is employed for measuring the height of the tool point from the planer table. The graduations on the inclined rule are such that the readings give the

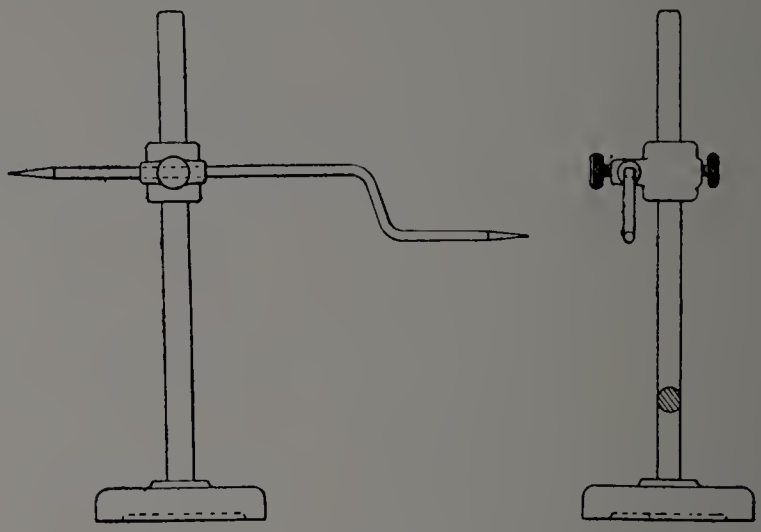


Fig. 346.

exact vertical height in sixteenths. The foot is clamped with one knurled screw, the scriber with another.

A form of scribing block is shown in Fig. 346, with a rigid scriber which cannot be swivelled, but it lacks some of the advantages of the latter type. It is handy, however, for making horizontal lines at various heights, and may therefore usefully supplement the gauges which have a wider range of adaptability.

The last illustration of a surface gauge is one of the micrometer type (Fig. 347). The principles embodied in micrometric instruments are explained on pp. 288, 291, so nothing will be said about them here. The instrument illustrated combines this fine method of measurement with the utility of the surface gauge. In

addition to these, large measurements in inches are provided for by the fitting of end measuring plugs of standard lengths.

In Fig. 347 the stem A of the gauge is hollow, and receives the plugs seen in the broken sections, measuring 1, 2, and 3 in. long respectively, and which can be used separately, or in combinations, giving a maximum range of 6 in. in height. The lowest plug rests on a hardened adjustable stud in a recess in the foot, by which any possible wear can be taken up. The upper end of the plug in use receives an abutment piece formed on the inner end of the arm B. These plugs give dimensions in even inches from 1 to 6 in. Dimensions between these are obtained by the micrometer C on the outer end of the arm B, which has a range of 1 in, reading to one-half thousandths, the end of the plunger D bearing on the surface of the work.

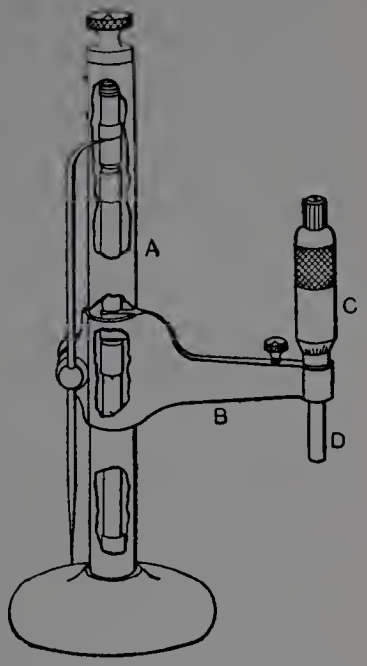


Fig. 347.

In these numerous designs of surface gauges or scribing blocks we have wandered far away from the simple instruments which the apprentice makes. They have developed from the plain gauge into very fine instruments of precision, capable of extremely fine adjustments, which are not only relative, but readable in absolute measurements. We shall also observe similar refinements in other classes of tools of common types. The utilities

Fig. 348.

of the gauge are therefore much enhanced, rendering it suitable to the higher demands which are now made upon the marker-out and the machinist than formerly.

The common scriber of the shops is usually made from a bit of steel rod, one end of which is bent round for marking upwards on surfaces that face downwards, and in awkward recesses, &c.

The central portion is either left smooth, or is twisted to afford a grip for the hand. Better instruments are manufactured by the insertion of the pointed portions into a central stock which is considerably larger than the body of the wire and knurled as in Fig. 348. The thicker ends of the points are also knurled similarly. The stock is shown in section in Fig. 349.

These instruments are used without any extraneous aid, save the guidance afforded by a straight-edge, or an edge having an outline corresponding with that of the piece which is marked from directly. The patternmaker uses a knife edge for scribing, but the machinist scribes with points only. The tool must be properly tempered to retain its keenness of point, and must be held at a very slight angle only with the edge from which the marking is done. In this way very fine lines can be marked accurately for centre popping and working by.

Fig. 349.

The scriber, or striking knife is used by woodworkers for marking lines on timber as guides for planing, cutting by the edge of a straight-edge, or of a templet in some cases, which becomes the guide to the knife. It is double ended, one end cutting in like a chisel, or a gauge point, the other scratching only. Bent scribers are used for marking in places that cannot be reached by a straight tool.

CHAPTER XXII.

Compasses and Dividers.

Distinction between Coarse and Fine Adjustment—Stiffness of Legs—Modified Forms—Combination Types—Trammels—Examples—Centring Balls—Parallel Dividers.

THE varied forms of compasses, dividers, and trammels will now be considered. Many of these bear strong resemblances to some forms of calipers, similar devices being employed in each for the purpose of effecting precise adjustments. The term divider is usually applied to those instruments which have spring heads, and compass to those which are hinged or pivoted. The first named are not quite so rigid as the latter, to which additional stiffness is afforded by the quadrant and wing nut. But the first are properly kept for small radii and fine precision work, the latter for larger radii and deeper lines, or on rougher surfaces. But the two types overlap constantly. For pitching out, or general dividing out, the screw fitted to a divider is better than the quadrant and wing nut. But the latter are often supplemented by a fine adjustment screw similarly to the calipers of that design. To work to close dimensions with any instruments having adjustable legs renders a means of fine adjustment indispensable, and therefore there are few high-class tools now made without that provision. Varied widely though these are, the beam compasses or trammels are equally so, having their coarse and fine adjustments, and lengthening points in many designs. For curves above a few inches in radius the trammels are essential, if for no other reason than to have the legs perpendicular to the surface of the work. And there is no limit save the rigidity of the beam to the radius of the curve which they will strike. All high-class instruments of the kinds here enumerated have both coarse and fine adjustments—coarse with thumb-screws, and fine with an independent screw of fine pitch. Some, like

the spring dividers, contain practically only the fine adjustment by the wing nut, a rapid movement for approximate adjustment of the points being accomplished by pulling the legs towards each other to release the friction next the screw, and then by running the latter along by the finger until the spacing of the legs is roughly that required.

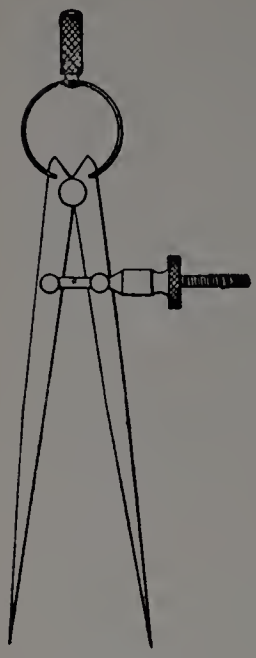


Fig. 350.

A most important point in the design of all compasses and dividers is stiffness of legs. This is quite consistent with lightness. Flimsy legs inevitably spring, and alter the truth of a circle, large or small, even during the act of describing it, and they chatter in the act of scribing. If used for setting out points of equal division, they will not mark equally, but give variable centres according to the degree of pressure exercised upon them, and the way in which they are grasped.

When taking dimensions from a rule with compasses or dividers, they are never started from the end, but in one of the divisions, usually the first from the end, which is more accurate than attempting to work from the end.

A good many dividers have a milled head standing up beyond the spring for the purpose of rotating them when striking circles. These resemble the ends of a draughtsman's small ink, pencil, and point compasses, and are more favourable to the rotation of the

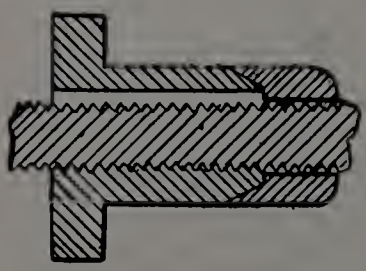


Fig. 351.

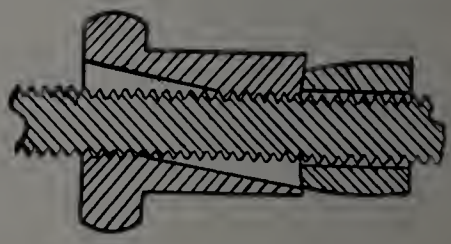


Fig. 352.

instrument than the handling of the spring itself, more especially in the case of small circles. Fig. 350 illustrates a pair of this type.

Instead of a solid nut of the wing or milled type, the devices shown in Figs. 351 and 352 are sometimes used. The legs being

pulled together by the fingers to relieve the nut of pressure, the latter is then readily disengaged from and slipped over the threads of the adjusting screw, until the approximate position of the legs is reached, when the nut is again allowed to resume its normal position of engagement with the screw for the purpose of making precise adjustments. The pressure of the legs on the nose of the nut causes the latter to grip the thread. This neat device saves much time and delays the wear of the thread in the nut, which is always a vulnerable point. Another type of this device takes the form of a spring chuck formed with the adjusting nut, pressure on

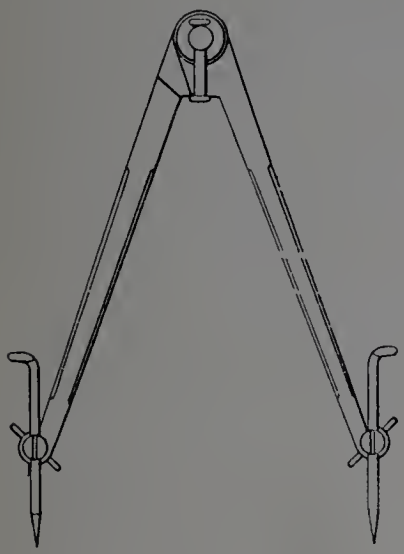


Fig. 353.

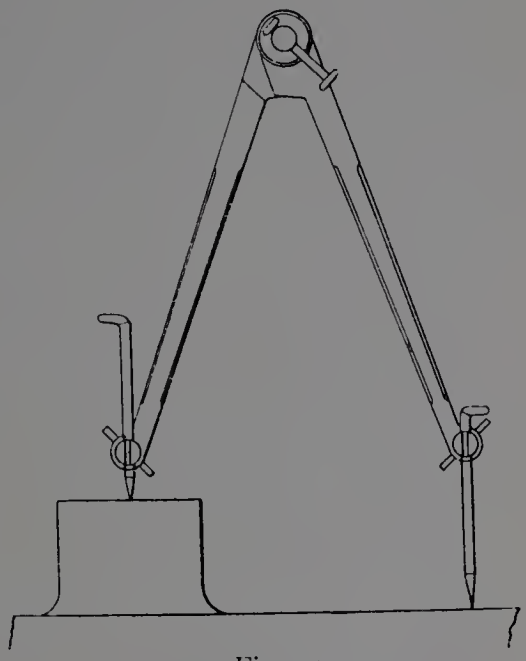


Fig. 354.

the nose of which closes the jaws in on the screw, but when the pressure is released they spring out naturally.

A modification of the compass consists in making the marking points distinct from the legs, and fitting them in grips (Fig. 353), instead of socketing the legs, as is often done. The advantages are that whatever the spread of the legs, the points can always be kept perpendicular to the surface of the work, thus avoiding all tendency to be forced outwards by the pressure of the hand. The same legs being curved at the opposite end, serve as calipers. Also, the legs being slid up or down in their grips can be used to strike curves on levels above or below that of the centre, as in Fig. 354. Further, the legs being straightened out into line,

serve as trammel points, Fig. 355—a moderate range of radii then being obtainable by bending the legs at different angles. The same instrument is shown in Fig. 356 with another pair of legs, which are used as compasses or as external calipers, Fig. 353 illustrating internal calipers.

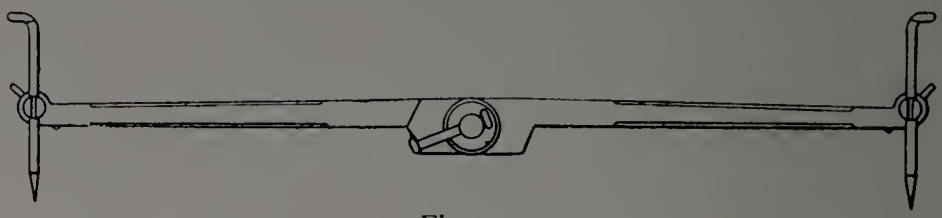


Fig. 355.

Though combination tools are not as a rule desirable, yet there are many exceptions. Men who have to work on out-of-door jobs know their advantages in saving dead load to be carried, and in not having to be bothered with a lot of tools scattered about. Besides the tool just described, a few examples are the following:—

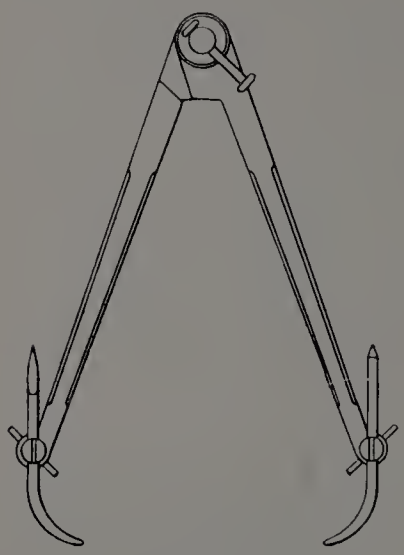


Fig. 356.

A pair of compasses with a hinged joint and quadrant wing with fine adjusting screw has its legs formed as sockets. Into these, two pairs of points, long and short, fit, also a pair of bent caliper legs, the curves of which may be turned inside or out to suit either form of measurement, and another leg with a centring disc for scribing circles round holes. Some of the Starrett fittings include ball points for striking circles round holes, to save the trouble of bridging across them and marking a centre. Thus a single leg or holder carries four interchangeable balls of $1\frac{9}{16}$, 1, $\frac{3}{4}$, and $\frac{1}{2}$ in. diameter.

A combination tool is shown in Fig. 357, in which compass and caliper legs are combined in one, to be turned about on their joints. The calipers are suitable for internal and external work, and the compass points are perpendicular.

A unique attachment to a tool consists simply of a sliding grip, two of which can be bolted to caliper legs. Each carries a scribing point, to be used as a compass or as hermaphrodite calipers, or, as they are more generally termed here, compass calipers; or the points can be used for measuring the bottoms of screw threads, or when the caliper legs are extended they can be used as trammel points.

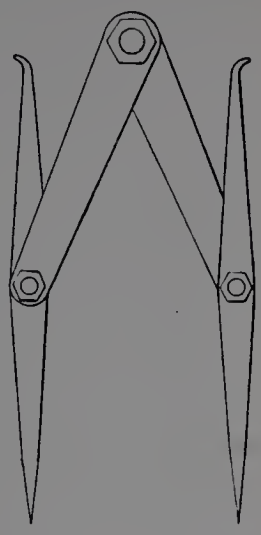


Fig. 357.

The tools of the compass, and scriber type all owe their precision value to their points, to the fineness of which is due the dimension termed the "thickness of a line," considered a fine degree of accuracy in handicraft, and is of course the finest measurement available in the system of working by marking out.

The limit to the use of the compass comes in when the legs are spread very much. They should not be used to their maximum capacity, because the angle of the legs is then so great that the points stand further from perpendicular than is consistent with accurate lining-out. A larger pair should then be substituted, or the trammels used. It is well to curve compass points inwards to correct the effect of setting them at an angle.

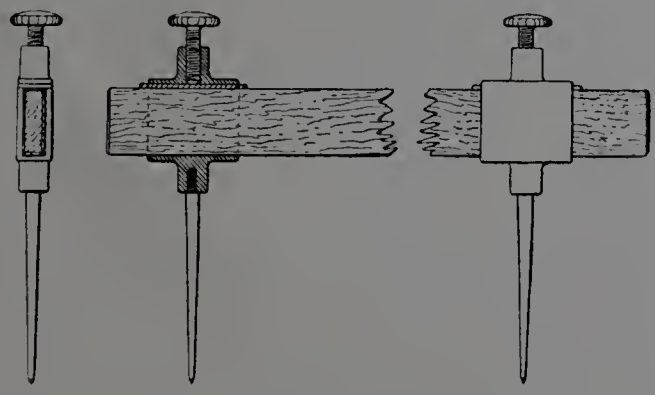


Fig. 358.

Trammels are varied in regard to their capacity for minute adjustments, and as combination tools. The common form comprises two heads with fixed points. They are slid along the beam (Fig. 358), which is of rectangular section, their points being set

upon the rule, and pinched by thumb screws above, which press, not directly on the beam, but on washers. In this general design of common trammels the heads are cast in brass. These are suitable enough for nine-tenths of the ordinary work done, but they lack the fine adjustment necessary to ensure high-class work. Every one who uses common trammels knows how difficult it is to get a precise result without a good many pinchings and slackenings of the screw. The longer the bearing which the heads take on the beam the better, in reason. The pins also should make a perfectly tight fit in their sockets, either by a driving fit or by screwing. In the best instruments one of the heads contains provision for fine adjustment by means of a screw, variously arranged, or by other means.

In the Starrett trammels fine adjustments are effected by rotating the points in their sockets, the points being made eccentric relatively to the shanks for the purpose. The legs pass up at the sides of the heads instead of being fitted below them, and the upper projecting portions are milled for the fingers to rotate them by. These are also combination tools, for caliper legs fit interchangeably with the points. One of these legs is jointed at the commencement of the curved portion, and has an eccentric thumb piece for effecting fine adjustments. Two special forms are as follows:—

One is a light extension trammel, the beam being made up in three sections, each of 14 in. in length, either of which can be united to the others by a socket coupling and grip nut. Both points and caliper legs are fitted into the heads. The latter slide on a bar of circular section, flattened on one side, to which they are gripped with a knurled nut that also grips the slides to the bar and the points in the slides. The points have fine adjustment by the eccentricity imparted to them, as just now noted. Friction springs retain them in place when the knurled nut is loosened.

Another trammel has the heads fitted to a wooden beam. As in the first example named, the points and caliper legs pass up at the sides of the heads, and are knurled above. Fine adjustments of the points and caliper legs are obtainable by the devices previously explained. Two pairs of points are fitted—the ordinary, and a pair of extra length for deep work. A set of four ball points, with a holder adapts the trammel for striking circles round holes of various diameters. In another type, fine adjust-

ment of one leg is effected by hinging it to a lug below its head, on which it is pivoted by a knurled nut and the action of a spring.

In one form of beam trammels, and also in parallel dividers, the long milled head by which these instruments are rotated is used for clamping the heads, which has some advantages over the ordinary thin head of a screw.

In one type of precision trammel one leg is fixed near one end, being pinched with a screw, and the other is adjusted by a vernier along a beam, graduated in millimetres.

The centring balls just now referred to are useful when a circle has to be struck round a small hole. When holes of medium and large size occur, they are plugged, or else bridged with a strip of wood or metal, and the centre located thereon. But in the case of small holes this can be avoided by using trammels having one leg formed as a solid disc of parabolic section in the vertical direction.

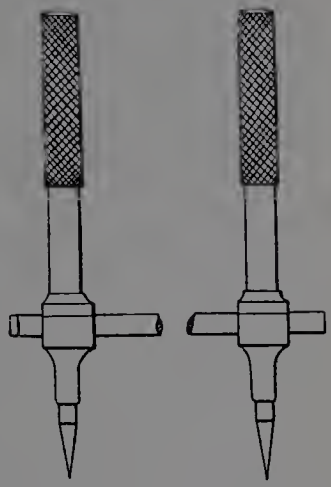


Fig. 359.

In a common American form of trammel the beam is made of $\frac{5}{16}$ in. round steel, with one side flattened. Circular slides are pierced to carry the points, and both points and beam are gripped by a partial turn of a knurled nut. In those trammels in which fine adjustments are effected by having the points eccentric to the axis of the steel, friction springs retain them in place while the nut is loosened.

In one of the Starrett trammels, which is also a combination tool, the heads do not embrace the beam, but are open-sided, so that a beam of any thickness may be used, and of any depth from $\frac{3}{4}$ to $1\frac{5}{8}$ in., that being the range of adjustment permitted by the clamping screw. The points pass down one side of the head, and are gripped by a screw at one side. The combination comprises long and short points, two pairs of caliper legs (inside and outside), and a set of four ball points, which cover a range of holes up to $1\frac{1}{2}$ in. Fig. 359 shows a pair of light trammel heads, which are clamped on a bar at any desired position. They are suitable for light work, and will do delicate marking.

A connecting link between the dividers and trammels is the parallel dividers (Fig. 360). In these, the scribing point is turned down from a beam which slides along and is adjusted in a perpendicular stem. The advantage of this design is that, as in the trammels, pressure on the head does not tend to spread the legs, but comes directly over the centre point.

There is a limit to the length of trammel beam which can be used, consistently with the obtaining of precise results. The smaller the trammel heads, the shorter must the beam be. Patternmakers and millwrights who often have to strike large radii keep a set of large heads for the purpose, fitting a beam of, say $1\frac{1}{2}$ by $1\frac{3}{8}$ in., or 2 by $\frac{1}{2}$ in. cross sections. Two or more beams of different lengths are kept, and the longest is stiffened by cambering it on the top edge, starting a foot or two away from the ends, and this is sometimes supplemented by screwing cambered strips on one side of the beam. In this way rigid but light rods of pine from 12 to 20 ft. in length can be obtained, beyond which dimension, radii must be struck by geometrical methods apart from the aid of trammels.

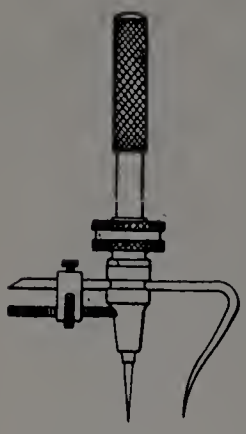


Fig. 360.

A wooden trammel is easier to make than one of metal, and is very serviceable, a bit of boxwood being the best material. The heads will be turned, rather than made rectangular, and the lower and upper portions which receive the leg, and the screw, bonded with a bit of ferrule. A nut let carefully into the upper portion of the head flush with the top face of the mortise receives the thread of the set screw.

CHAPTER XXIII.

Calipers, Vernier Calipers, and Related Forms.

Essentials in Calipers—Proportions—Weight—Adjustability—External and Internal Types—Capacity for Adjustment, how met—Special Forms—How to Use Calipers—Examples—Compass Caliper—Keyway ditto—Vernier Calipers—Principle of the Vernier—Difference between Vernier and Micrometer—Caliper Rules—With and without Verniers—Examples of Vernier Calipers—How to Read—Examples of Various Forms.

THE old-time hands never had so rich an assortment of calipers as that which is offered in such bewildering variety to-day, even excluding the vernier, and micrometer calipers which form separate great classes.

It is the custom to hold calipers in less esteem than formerly, due to the fact that gauging has superseded them in many departments of practice. But in the average run of common and general work they must always retain their utility. And as engineering practice becomes more and more exacting, increasing care is bestowed on the design and construction of these instruments, and greater care and refinement in handling them is demanded.

The three essentials in a caliper are proper proportions, weight, and adjustability. In the ideal forms, both of outside and inside calipers, proportion and weight are so balanced that the instruments embody the minimum of elasticity with the minimum of weight. Heavy calipers are not sensitive enough for fine measurements, yet stiffness is absolutely necessary. This is secured by the tapered form or the cantilever style. One often sees home-made articles too narrow next the pivot, and too broad next the points, no very accurate measurement being possible with these. Another detail is, perfect fitting between the pin and its hole, and between the opposed faces around the pivot. Another is fine points, so that but a slight surface comes in contact with the work, which facilitates reading off or otherwise testing the dimension taken.

The functions of the external and internal calipers are too obvious to call for remark beyond this—that they are used either to measure a dimension, and test it on a rule, or against another caliper, as inside against outside, and *vice versâ*, or against a fixed gauge, or set to a dimension and reducing the work thereto. It is essential that the frictional hold of the joint shall be sufficient to ensure the retention of the legs in position during handling; and herein lies much of the art of calipering—namely, to take dimensions and transfer them, or check them without alteration. In large heavy calipers a mere change of position from vertical to horizontal will alter the measurement. The calipers should be

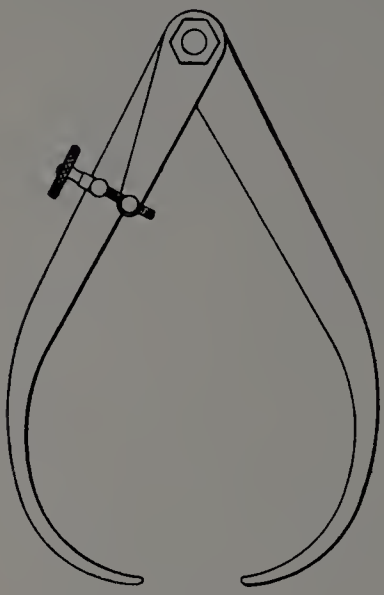


Fig. 361.

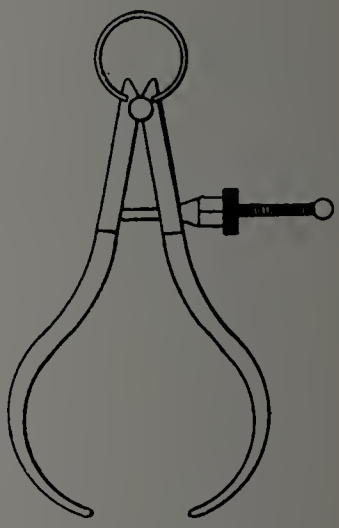


Fig. 362.

gripped at the pivot, not by the legs, when in use, and minute differences in size are produced by gentle tapping of a leg on the surface of any object.

This brings us to the third condition named—that of capacity for adjustment. Numerous devices are in use to avoid the method of adjustment obtained by merely tapping the legs, though in the hands of a careful man it is very doubtful if any device is more sensitive than that of the sense of touch.

An old method is one borrowed from the compasses—namely, a slotted quadrant wing, and thumb nut, by which the caliper legs are secured in any position. This does not afford any exact

means of adjustment, but only security of fixing. Such calipers are adjusted with light taps, with the wing just frictionally tightened.

Minute adjustment is provided in some examples by a compass device also, that of a fine adjustment screw at the termination of the quadrant bar. The wing nut is tightened with the caliper legs at an approximately correct position, and then fine adjustment is effected by the screw.

This also is an old device; but there are many later ones, some of which are preferable. In one form a flat washer plate is fitted at the joint of the legs, and is extended a portion of the way down one leg, and has its end formed as a nut in which an adjusting screw moving parallel with the face of the leg works (Fig. 361). The screw is carried in a stud fastened into the leg. In other types nuts are used. The legs are connected by a rod which is screwed for a considerable length like the screws of spring dividers (Fig. 362). But instead of running a nut back over the screw, to the rapid wear of the latter, and also with waste of time, the nut is both screwed, and plain in the hole. When the legs are held together, releasing their end pressure on the nut, the latter can be slid along by the smooth portion of its hole. When the pressure due to the spring is allowed to come on the nose of the nut, the threaded portion of the latter engages with the screw, and fine adjustments can be effected as usual. In another form of caliper a lock nut is used to retain the legs in the position set. Fig. 363 has a plain solid nut.

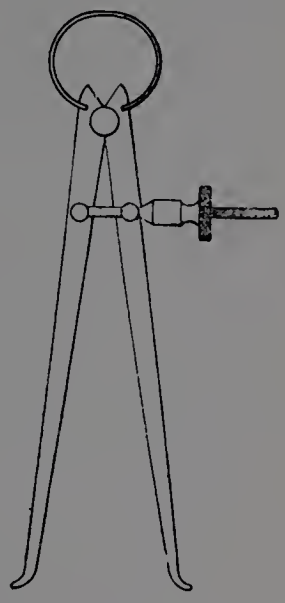


Fig. 363.

There are many instances in which chambered or recessed portions of work have to be measured, from which the calipers cannot be withdrawn without shifting their legs. A device to get over this trouble is the provision of an auxiliary wing, which has a slot into which a stop on one leg is pushed, and which ensures the same setting after the leg has been loosened therefrom.

Another type of caliper is designed for reading off the dimen-

sion taken by the legs, on a quadrant at the other side of the pivot. In one form this is read by a pointer only, but in others a vernier is employed. The vernier is carried in an extension of one of the caliper legs, and moves over a quadrant carried in an extension of the other leg (Fig. 364). In a modification of the latter a locking handle is fitted to the pivot (Fig. 365), to prevent risk of the legs being shifted. In another instrument a straight bar takes the place of the quadrant, and the vernier moves over it, the bar being pivoted at one end (Fig. 366).

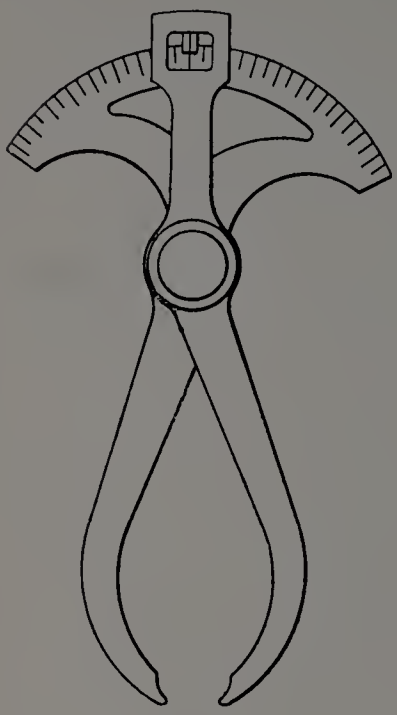


Fig. 364.

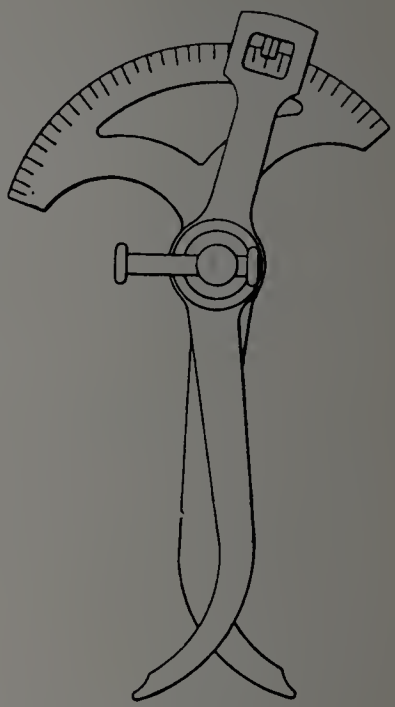


Fig. 365.

To use calipers properly is an art that has to be acquired, and to which constant practice and a delicate sense of touch contribute. Two men will hardly measure the same piece of work exactly alike, as so much depends on the way in which the calipers are handled.

In the art of calipering, a good man will be safer with poor calipers than a clumsy one with the best instruments. The spring of calipers is very deceptive, and may easily lead one astray, hence the strength of the case for fixed gauges; yet the calipers must ever fill a place of their own. The amount of spring will depend

on the way in which they are held—in but a slight and almost imperceptible degree in the smallest, but very perceptible as size and weight increase. The proper way to hold heavy calipers over work is perpendicularly for outside work, and horizontal for inside, so that any possible drop of the leg due to weight is eliminated. Another point is, that in whatever position a pair of calipers is held (the smallest sizes excepted) to take a dimension, it should be held similarly when checking it either by another pair, or by a rule. It is more necessary to observe these precautions in slender, springy, badly-proportioned tools than in those with good, large, well-fitting joints and well-tapered legs.

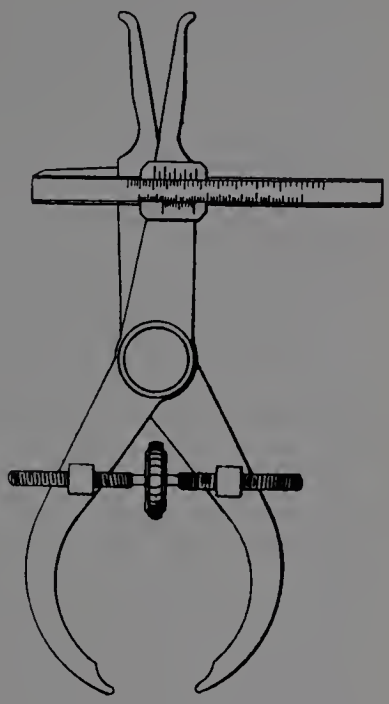


Fig. 366.

It is easier to work to rule dimensions by the aid of calipers than to produce the various fits required in different classes of work by them. Driving, and easy fits are properly work for the gauges, because the calipers do not indicate the exact size of a whole circumference as do the gauges. When these fits are tested with calipers, the internal are tried in the external, and the degree of tightness, or easiness present is the means by which the workman estimates the measure of the fit for driving hard, as in press fits for exact fitting, or for free fitting as required in journal bearings. To measure the degree of contact of the fine caliper points correctly, no coercion or pressure must be exercised on the legs, one point of each being maintained in contact by leaning them against the forefinger of the left hand, the other points being moved one over the other.

In this connection the double calipers may be mentioned—namely, those which combine external and internal legs respectively on opposite sides of the pivot. The design gives internal and external measurements alike at the opposite ends. But they are not permanently reliable for the finest work, because they wear unequally. For common use they fill a useful place.

The spring of calipers is utilised by the workman, turning what is an evil in some cases into a blessing. The amount of spring, though very slight, is frequently sufficient to enable one to judge how much to reduce a piece of work as it nears completion. Thus, a caliper being set to a finished diameter, and being firmly jointed, the spring due to forcing it over, or into the work will indicate a full dimension, without being sufficient to shift the setting at the joint. It is, in effect, the same as the difference between the "go-on" and the "not-go-on" of the fixed gauges, with the difference, that in the hands of an experienced man it indicates by just how much the work must be reduced to bring it to size. It does not give the difference in hundredths of an inch, but it is none the less efficient. The difference between a tight fit, more or less, is easily recognised, and that stage at which the calipers make the slightest contact without the exercise of force and without slop is readily detected.

The practice of trying calipers over work which is running in the lathe is one that is often adopted. It of course tends to wear the caliper points, and may, when roughing down is being done, shift them slightly. But when testing fine finishing dimensions, the work should be stopped before putting on the calipers.

Correct measurement can only be ensured when calipers are held square with the axis of the work. If they are allowed to get across, though ever so slightly, they will not tell the true diameter. To detect the truth of the right-angled position the caliper is steadied on one point and moved, or the attempt is made to move the other point longitudinally, to see whether it fits easier or tighter. This precaution is not necessary in small diameters, but it becomes so in large ones, and it is more essential is checking internal than external sizes. An illustration of a similar kind may be noted in the rod gauge when checking the bore of a large cylinder.

From this aspect the width of caliper points is important. Some workmen like wide points, because they tend to set themselves square across the piece measured, and with this object they are often spread out. These are all right for average work, but not for the finest. They are useful in wood turning and roughing down metal, but not for much besides. If wide points are used for fine precision work, the unequal wear of the points renders it difficult to locate a dimension. And if they are rounded length-

wise, as is sometimes done, they might just as well be narrowed at once.

Another way in which calipers are used is to employ two pairs, one to rough down by, and one to finish. The utility of this plan comes in when a number of similar pieces have to be turned alike. In such a case the locking types are best, because they are not liable to accidental alteration in size. These are then employed just as fixed gauges.

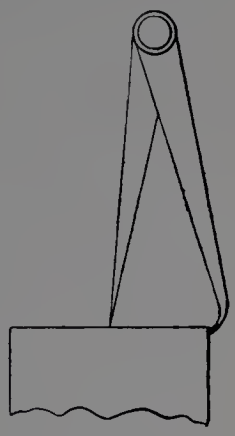


Fig. 367.

The instrument termed a compass caliper, or by some, hermaphrodite caliper, is extremely useful. It is a scribing tool, the caliper leg controlling the movement of the compass leg. It can be used as in Fig. 367 or Fig. 368. In the one case—which is its most useful application—its caliper point is brought into contact with the circumference of a circle at various points, and its compass point strikes several short lines, the intersection of which indicates the centre of the circle. In the other application, lines can be drawn parallel with any surface, external or internal, curved or straight. The value of this tool lies in the greater delicacy of contact of the caliper leg over that of a compass point if used for the same purpose. A manufacturer's form of this instrument is shown in Fig. 369, in which the caliper end is double, bent to right and left, and the compass point adjustable for length.

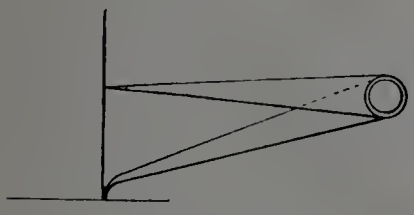


Fig. 368.

Another special form is the keyway caliper (Fig. 370), so called because it is used for checking the distance of a keyway or groove from a surface. The straight leg is inserted and lies flat against the bottom of the key groove, while the caliper point checks its depth from the outside.

At this stage we leave the calipers of the types hitherto considered, for these alone do not fulfil the requirements of present-day manufacturing. Extreme accuracy is attained with these appliances, but not extreme precision: mutual fitting, but not exact absolute dimensions. For these we must go to the vernier,

and the micrometer calipers, each of which provides, though in a different fashion, for the reading off, or fixing to dimensions measured in hundredths, and thousandths of an inch, or tenths, or hundredths of a millimetre. These tools are not in such common and general use as the calipers already noted, though they are plentiful in shops where special classes of manufacture are carried on, and in tool-rooms. They are too fine and expensive to be knocking about on every ordinary machine and bench, for which the fixed gauges, to be considered later, are more suitable, yet in their spheres they are now indispensable. As yet they are chiefly manufactured in America, Germany, and France.

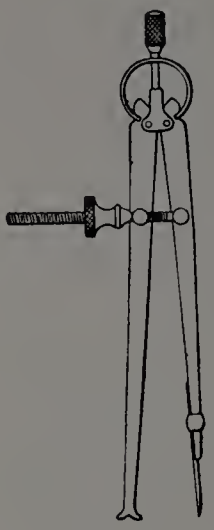


Fig. 369.

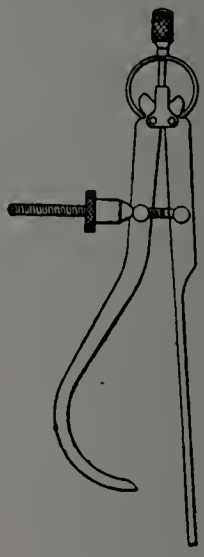


Fig. 370.

The methods of the marker-out form a very important section of modern as of the older practice, since in many classes of work they cannot be dispensed with. A man with a scientific turn of mind would regard them all as coarse—akin to the methods of the carpenter and joiner and mason, as in some degree they are. But they are redeemed from the imputation of coarseness by the methods of checking which follow. It is substantially correct to say that no decent piece of work is ever completed by reference to the lines and centre pops alone which are laid down by the marker-off without further check. In fact, we must regard these in the highest practice as simply a rough approximation to the forms and dimensions desired, and which have to be obtained by

devices and appliances much finer than those employed in the mere work of lining-out.

In considering the various methods of checking adopted we must remember our cardinal subdivision into rule, and gauge measurement. The vernier caliper, or caliper rule, and the micrometer caliper each combines the sense of touch with that of vision—that of the gauge with the rule,—and hence these two instruments are the sheet-anchors of scientific workshop measurement, having many applications, not only to the actual tools used for measurement, but also being embodied in precision machines. An explanation of these, lying as they do at the basis of so much in modern measurement, should preface illustrations of the instruments in which they are embodied. But first we will dispose of the caliper rules.

The caliper rules of plain type give direct readings in English, or metric measure. In the plainest forms they do not include a vernier reading, but a slide either moves along a graduated edge, or is drawn out, and is itself graduated, in addition to the graduations on the edges of the rule. Such rules are short—usually from 4 in. to 8 in. in length, and rather less in the effective caliper opening. The divisions on different rules are made in a wide range to suit all requirements, English and metric. They are accurate in effecting direct readings within the limits of the graduations, to 64ths in., 100ths in., or half-millimetres, but nothing finer is practicable, excepting full and bare dimensions. They are used chiefly for ready measurement and reference, sufficiently accurate in general work, and for measuring rods, tubes, and stock, &c. These rules without a vernier, comprise a large number, made in boxwood, ivory, brass or steel. The jaws are more liable to wear than the high-class articles in which the jaws are of steel and hardened.

A much improved form of sliding caliper is illustrated in Fig. 371. The beam is graduated on one side into 64ths, and on the other to 100ths, of an inch. The section of the beam, seen in end view to the left, combines strength with lightness. There is no friction or wear between the heads and the scaled faces. The two loose heads permit of fine adjustments by the locking of the right-hand one to afford resistance to the slight frictional movement of the adjustable jaw, effected by the milled head.

The vernier has long been employed in astronomical instru-

ments, having been invented so long ago as 1631 by Pierre Vernier. In its earlier applications it was made with one graduation less than those on the instrument to which it was fitted—that is, ten of its subdivisions were equal to eleven on the principal scale. Later it was made with one graduation more than the corresponding portion of the main scale. The principle is the

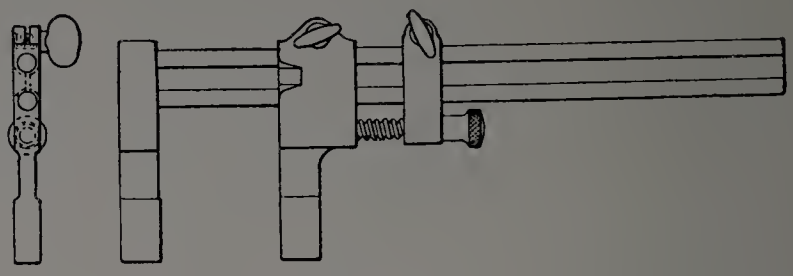


Fig. 371.

same, but the reading is rendered easier. The vernier in the workshop is used for reading-off dimensions directly to a thousandth of an inch by the inspection of the unassisted eye, which could not of course be done by simple divisions on a rule, for which one-hundredth of an inch is extremely fine.

The principle of a vernier is illustrated in the diagram Fig. 372. A represents a portion of a rule having its inches divided into tenths; B the vernier, having a length of nine of these parts divided equally into ten. As the sum total of the ten divisions on B is $\frac{1}{10}$ in. short of 1 in., it follows that each division on B must measure $10 \times 10 = 100$th of an inch less than the divisions on A. Further, if the line 1 on B is $\frac{1}{100}$ in. short of 1 on A, then line 2 on B must be $\frac{2}{100}$ in. short of 2 on A, and line 3 on B $\frac{3}{100}$ in. short of line 3 on A. A finer degree of variation can be obtained by either increasing the number of subdivisions or by increasing the length of the vernier. Thus much for the principle.

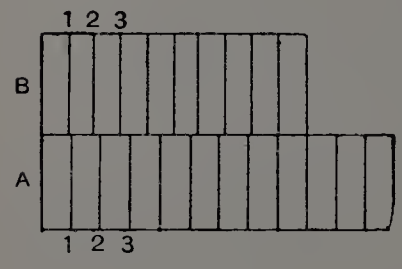


Fig. 372.

The micrometer method of measurement is not the same as the vernier, though the results obtained are similar. It embodies the minute subdivision of the pitch of an accurately-cut screw of

fine pitch by means of divisions around a boss that encircles the screw. One complete rotation of the boss advances the screw through a length equal to its pitch, and of course a portion of a revolution, the amount of which is regulated and read off on the divisions round the boss, advances it by a fractional portion of the pitch. This is the principle; the differences in micrometer calipers are those only in detail, such as to ensure perfection of the fitting of the screw in its nut, and to compensate for wear, and in special adaptations of the micrometer calipers to the varied requirements of the shops. There is one exception, however, to the above—the fitting of a circular vernier to calipers for extremely fine measurements, as ten-thousandths of an inch. Details of these instruments are given in succeeding pages.

The vernier caliper in its most common form by Brown &

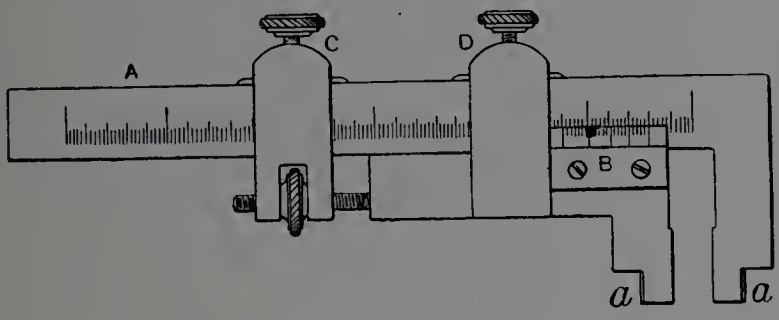


Fig. 373.

Sharpe is shown in Fig. 373. It comprises a beam or bar, two heads, a slide, and caliper jaws, both internal and external. The internal jaws are recessed to clear the work, leaving a comparatively short length only for the working faces, which are hardened and ground. It reads to 1000ths of an inch, or 64ths, and is also made to read to 50ths of a millimetre.

The bar A is divided into inches. To read to thousandths, each inch is divided into ten parts, and each tenth into four, so that each inch is subdivided into forty. The vernier B is divided into twenty-five parts, which correspond in total length with twenty-four parts, or twenty-four fortieths of the bar. Each division on the vernier is therefore shorter than each division on the bar by 1000th of an inch. The same relation would exist if the rule were divided into 50ths of an inch, and the vernier have 20 lines to 19 on the rule.

The way to take a dimension is as follows:—In the type shown in Fig. 373 the jaws are adjusted by hand to nearly grip the work. The thumbscrew on the head C is then tightened, gripping the head on the bar. That on the head D is tightened only just sufficiently to permit fractional movement between the head and the bar. The screw below the head C is turned by its milled head to move the sliding jaw D along, and make exact contact between the jaws and the work. Then the screw in D is tightened further, so fixing the measurement.

To read the dimensions so obtained, remember that if the zero point on the vernier corresponds with the zero point on the bar, the caliper would be closed, and each dimension would differ from the other by 1000th of an inch until they again corresponded at the line 25 on the vernier. When the caliper is set open, see

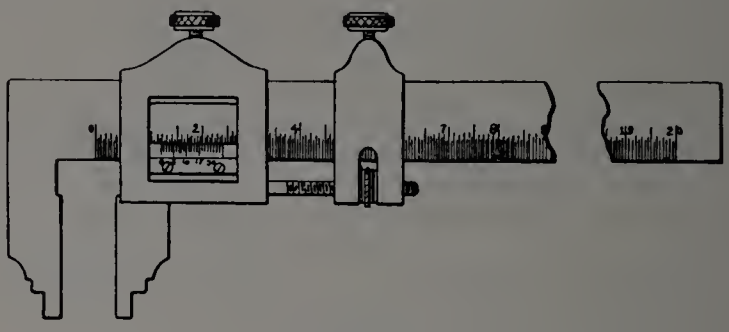


Fig. 374.

how far the zero points have been moved from one another in inches and parts. Count the number of divisions upon the vernier until one is found which coincides with one on the bar. Then these divisions will have to be added to the distance between the zero points read off directly on the bar. It is usual in reading to call the tenths 100,000ths—0.100, and the 40ths, or fourths of tenths, 25,000ths—0.025.

To set the calipers to a dimension, remember that when the line next to the zero line on the vernier B corresponds with the line next the inch line on the bar, and beyond the inch, it is set to 1000th of an inch. If set to the line within the inch it is 1000th less than an inch. Hence to set the instrument to a definite dimension, count the number of divisions, and add to or subtract these from the nearest whole inches.

Internal dimensions are taken by the jaws *a*, *a*, which are

rounded to permit them to enter the smallest hole which they will take. Here the diameter of the jaws when closed must be deducted from the reading taken by the vernier. This diameter is given in 1000ths for different calipers.

In some of the vernier calipers the divisions on the bar are into 16ths, and the divisions on the vernier are eight in $\frac{7}{16}$ in.; so making a difference of $\frac{1}{128}$ in. on each one, $\frac{1}{64}$ in. on every two, and so on. Others have one side graduated thus, and the side opposite into 50ths, with the vernier to read to 1000ths.

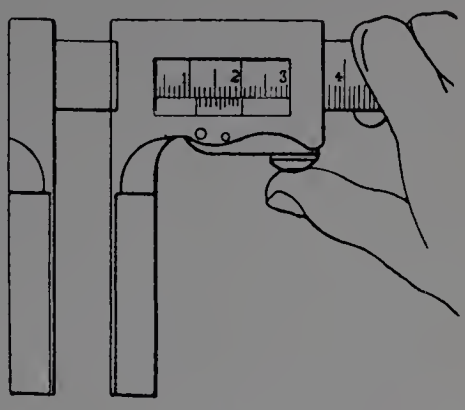


Fig. 375.

Fig. 374 is a German made caliper on a Brown & Sharpe model, which is divided into millimetres on one edge and into inches on the other. It embodies inside and outside measurements. The screw with milled head on the right hand head affords the means of precise adjustment of the right hand jaw.

One of the features that marks some German vernier calipers

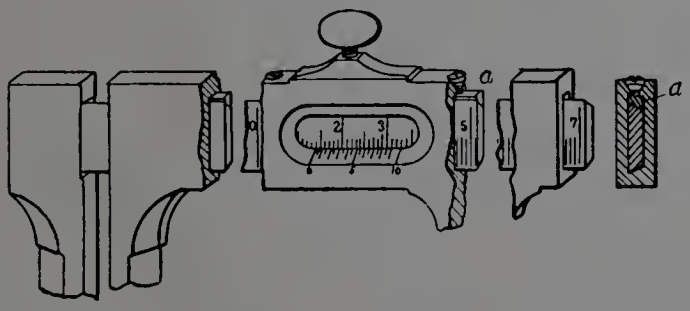


Fig. 376.

is the substitution of a spring lever for locking the sliding head, for the screw pressing on a spring interposed between it and the beam. One of these is seen in Fig. 375.

In a French vernier caliper (Fig. 376), the bar is trapezoidal in section, and the pressure of the screw is taken on a setting-up strip *a*, which is adjusted with two set-screws. The horn on the bottom of the movable head receives the pressure of the thumb

in making adjustments. In a lower grade of vernier caliper of German manufacture (Fig. 377), the adjusting head is omitted,

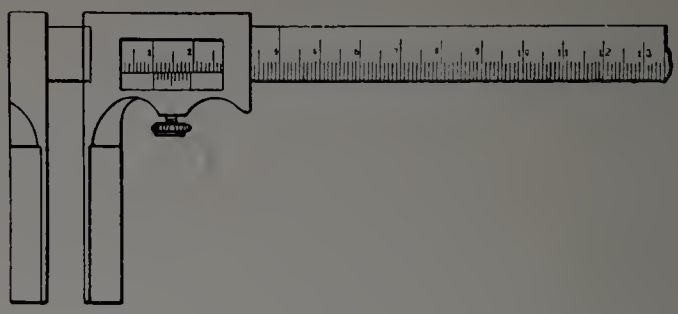


Fig. 377.

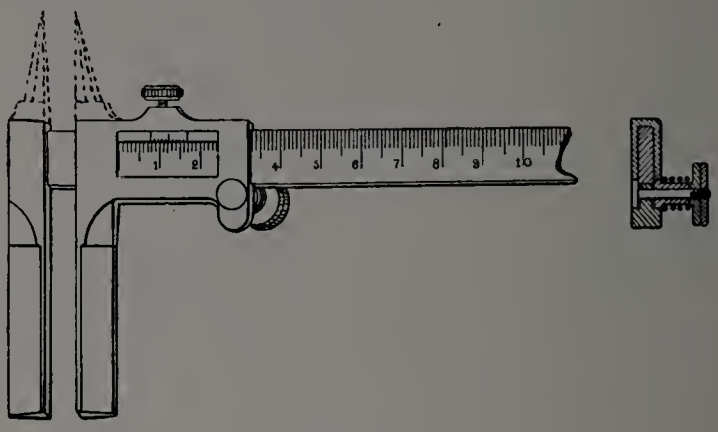


Fig. 378.

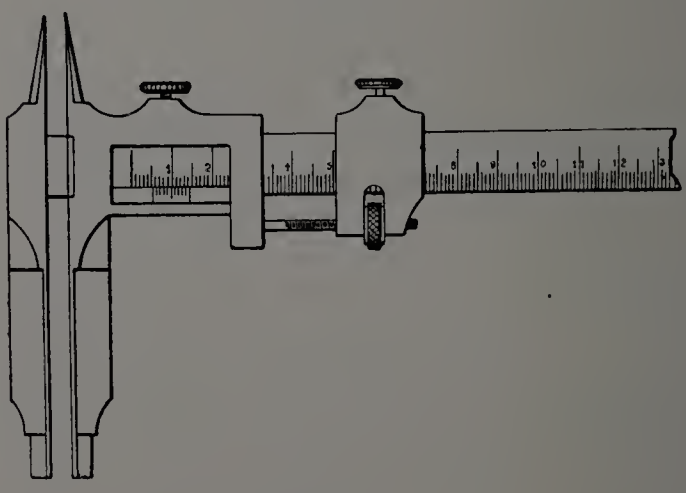


Fig. 379.

and the head and vernier are moved by the pressure of the finger on the horn, secured by a screw with milled head beneath.

A special form of vernier caliper is illustrated in Fig. 378. A pair of friction rolls is a substitute for a micrometer screw, in making adjustments of the movable blade. These rolls bear by their edges against the beam, and their pressure is adjusted by the coiled spring and two milled nuts. The sliding head is clamped by a screw above.

A good many vernier calipers are made with compass points (Fig. 379), prolonged on the opposite side to the jaws, the points being screwed in. Compass measurements may thus be set, or read off with the fine precision obtainable by the vernier. In some instances, as in Fig. 380, the points are made adjustable for wear. In numerous instances the bar of the instrument is utilised as a depth gauge, a set of graduations being marked from the end of the bar farthest from the head.

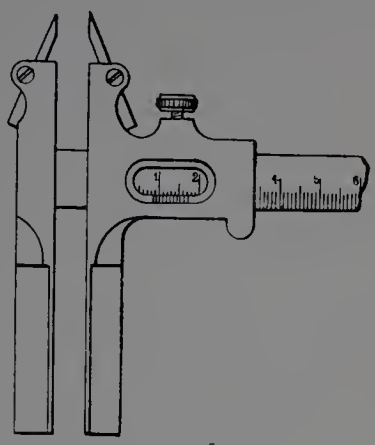


Fig. 380.

In some vernier calipers the cheeks or faces against which the measurement is taken are made separately from the bodies. They are of tee section, and fastened to the bodies by three screws each. The advantage is that these alone are hardened,

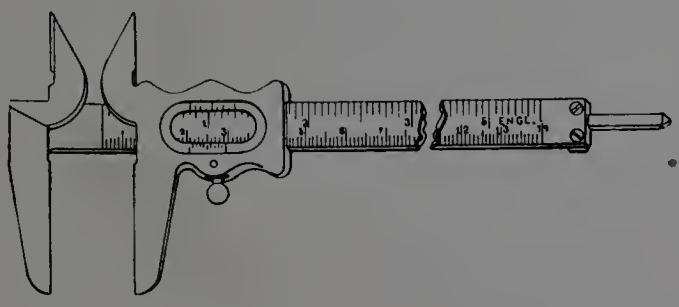


Fig. 381.

and there is no risk of the jaws becoming fractured by being made too hard, while they can be replaced without the necessity for making new jaws. The heads are prolonged on the side opposite to the jaws, and are slotted to receive steel compass points. The beam is graduated to serve as a depth gauge. The movable jaw has an eccentric fitting, by which it is clamped

to the beam, locking being effected by depressing a lever. The jaw is reversible, so that it can be used as a marking gauge for parallel lines. A small circular plate is provided to fit on the end of the solid head, to permit of the instrument being stood on end

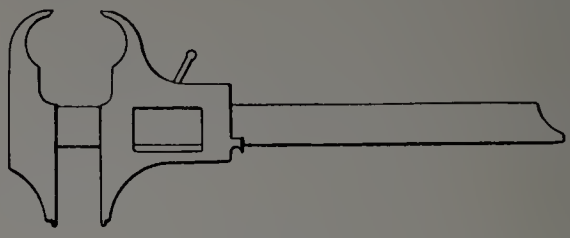


Fig. 382.

and used as a scriber, the plate sliding on a surface, and the point in the movable slide scribing the line.

The beam calipers are also made in inside and outside forms, as in Figs. 381 and 382, so that shafts and their holes can be measured while the caliper indicates the size of both.

CHAPTER XXIV.

Micrometer Calipers.

Principle of Design—Mechanism of—Details in combination with Vernier—Taking up Wear—Various Forms Described—Horseshoe Type—Beam Micrometer Calipers—Screw Thread ditto—Gear Teeth ditto.

THE principle of the micrometer caliper is simple, but the details of its construction call for a high degree of mechanical skill and care.

The Whitworth measuring machine and the micrometer caliper have this in common, that fine divisions are obtained by subdividing the pitch of a screw by means of a micrometer that contains a number of equal divisions. In the Whitworth measuring machine the screw has 20 threads to the inch. It is turned by a worm wheel of 200 teeth, actuated by a single-threaded worm, and a micrometer wheel on the axis of the latter has 250 divisions on its circumference, so that a movement of $20 \times 200 \times 250 = 1{,}000{,}000$ in. results from moving the micrometer wheel on the screw through one division. In this machine a feeling piece with parallel faces is introduced between the end of the work to be measured and the sliding piece. The difference on one millionth of an inch is sufficient to cause the feeling piece to be suspended or to fall of its own gravity. This piece in later measuring machines by the Pratt & Whitney Company is not placed in contact with the work to be measured, but caliper jaws are fitted inside one of the headstocks to receive it. It fulfils this useful function, that in testing standard gauges in the machine the behaviour of this piece affords an indication of the conditions of pressure between different gauges. In the Pratt & Whitney machines a variation of a hundred-thousandth of an inch is thus appreciable. Machines of this class, which cost over a hundred pounds each, are used for testing only. Pocket micrometers only

cost from a pound to thirty shillings, reading from thousandths to ten-thousandths.

Fig. 383 illustrates a micrometer caliper to read to thousandths of an inch. It embodies a screw, concealed, in one piece with the spindle A, having a pitch of forty to the inch. The barrel B is also graduated forty to the inch on a line parallel with the screw.

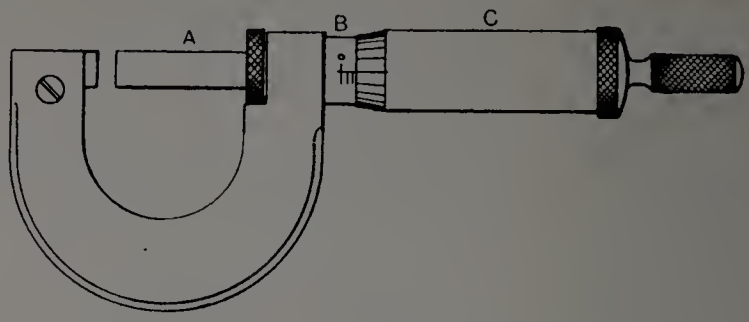


Fig. 383.

Each graduation therefore equals the pitch of the screw, and therefore the distance traversed by the screw during one revolution $= \frac{1}{40}$th, or $\frac{25}{1000}$ths of an inch. The thimble C, which fits the barrel closely, has its edge bevelled to facilitate reading the divisions there, which number twenty-five. Each division indicates that the screw has made $\frac{1}{25}$th of a revolution, consequently

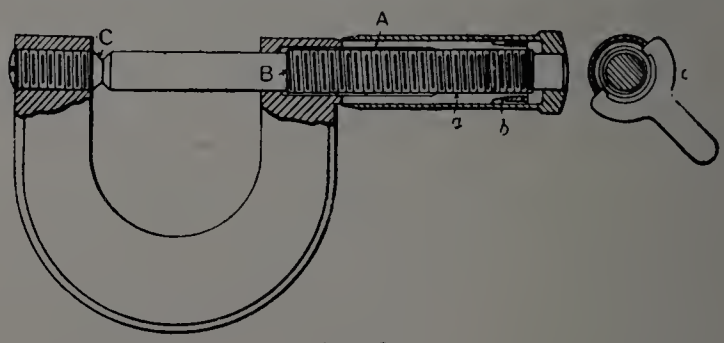


Fig. 384.

that the opening of the caliper has been altered by $\frac{1}{25}$th of $\frac{1}{40}$th of an inch $= \frac{1}{1000}$th. To read a dimension, therefore, the number of divisions visible on the barrel A is multiplied by 25, and the number of divisions on the bevelled hub of the thimble is reckoned from zero to the line which happens to correspond with the line of divisions on the hub. The figure illustrates one of the Starrett instruments, which has a knurled piece on the right-hand

end of the thimble by which the rotation of the screw is speeded about three to one for making rapid adjustments. The spindle is also locked in any position by the knurled nut next the U-shaped arm.

The mechanism of the Brown & Sharpe calipers is illustrated in Figs. 384, 385, and 386, the first representing the earlier, the second the later design. In Fig. 384 the barrel A is in one piece with the U-shaped arm, affording greater rigidity than was secured in some early types in which it was screwed into the arm. The rear part of

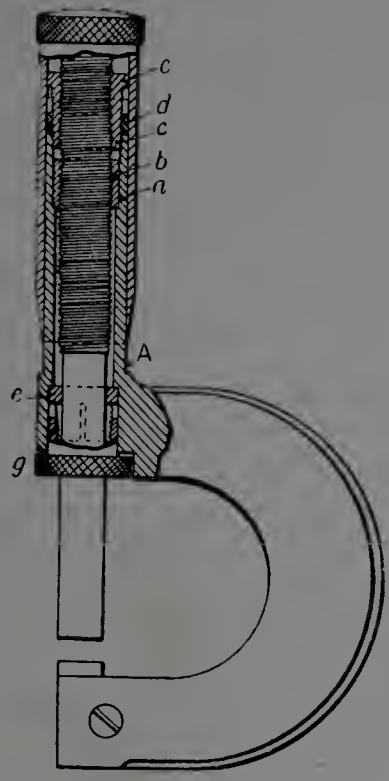


Fig. 385.

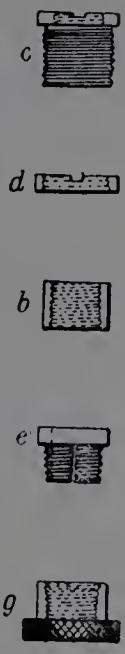


Fig. 386.

the barrel is screwed internally to form a long nut *a*, through which the micrometer screw B passes. The nut is split longitudinally, and encircled by a tapered clamping ring or thimble *b* to maintain a close fit as the parts become worn. A wrench *c* is used for turning the ring, to get at which the thimble A is run off sufficiently to expose the ring. The spindle portion beyond the screw B is made cylindrical to pass through the boss in the U-shaped head, where it makes a close fit, and this and the enclosure of the screw at the rear end protects it from dust and injury. The anvil C

makes a close fit in its boss, in which it can be turned from time to time to compensate for the wear of the faces against which measurement is taken.

In the improved form, Figs. 385 and 386, more detail is introduced, but the screw is supported better along its length, wear is more readily taken up, and a clamping device fitted. The barrel A, in one with the U-shaped arm, has sundry shouldered recesses to receive various sleeves which are seen in place, and separately, similarly lettered in Fig. 386. Into that portion of the barrel farthest from the U part, at the enlarged portion *a*, a screwed sleeve *b* fits, threaded to take the micrometer screw. Another screwed sleeve *c* behind this assists in supporting the micrometer screw which runs through it, and in taking up wear. It is threaded externally to engage with an internal screw cut in the barrel, and with one in the ring *d* which abuts against the end of the barrel and forms a lock nut. The upper end of *c* has an angular flange, the diameter of which is the same as that of the barrel, and is threaded internally to fit the micrometer screw. The screw threads in *c* and *d* are finer than those of the micrometer screw, as being more suitable for purposes of fine adjustment. The plain end of the micrometer screw is encircled by a ring *e*, having a split tapered boss threaded externally on the taper to receive a sleeve *g*, threaded to fit the taper, and having a knurled head coming outside. The rotation of the milled head clamps the split boss around the screw spindle, locking it in position.

Ordinary micrometer calipers do not go beyond the thousandth graduations. But lesser readings can be taken by subdividing the twenty-five divisions around the thimble and judging by the eye, so that half, or quarter of a thousandth can be estimated pretty closely, corresponding with the "full" and "bare" dimensions so commonly made. But a thousandth is a coarse dimension. This difference in external and internal gauges would make quite a slop fit. If fine measurements are wanted, a circular vernier is embodied in the caliper. Ten-thousandths of an inch can be read in this way by the eye without any guessing at subdivisions. These calipers should only be kept for the finer dimensions, in order to avoid excessive wear, which would soon impair their accuracy if used indiscriminately for the coarser measurements.

The vernier is seen in Fig. 387 at A and B. There are ten divisions, which occupy the same space as nine divisions on the

thimble (see upper Fig. A). When a line on the thimble at A coincides with the first line of the vernier, the next two lines to the right differ from each other by one-tenth of the length of a division on the thimble, the next two by two-tenths, and so on. When the caliper is opened, the thimble being turned to the left, the passing of one division by a fixed point on the barrel indicates that the caliper has been opened a thousandth of an inch. Thus when the thimble is turned so that a line on it coincides with the second line of the vernier, the thimble has moved one-tenth of the length of one of its subdivisions—that is, one-tenth of one-thousandth, or one ten-thousandth of an inch, and so on. To read the caliper, therefore, the main divisions, or thousandths, are read off as usual; then the number of divisions on the vernier, commencing at 0, until a line is reached which is coincident with one on the thimble. One ten-thousandth is added for each division.

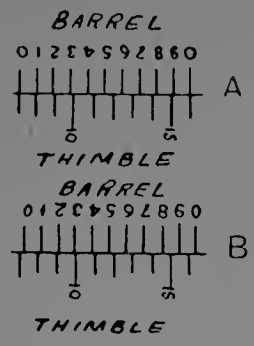


Fig. 387.

The difficulty with all calipers and gauges is the wear of the faces, which is the reason why line measurements instead of end measurements are adopted for all ultimate standards of reference. But end measurement is indispensable for ordinary work, and the only practical device for instruments required for constant and ready service. In the micrometer calipers the wear causes no inconvenience, because it is taken up at the anvil end by readjustment of the abutting piece. To facilitate this, the best calipers have a standard gauge in the form of a disc 1 in. in diameter, for insertion between the jaws of the caliper.

In the Bellows micrometer the method of adjustment is that shown in Fig. 388. Wear on the screw is taken up by a nut encircling the screw, and tapered on the outside to fit a taper in the barrel. The nut is split down one side and partly down the side opposite, and it is closed by turning the nut A behind it, forcing it down its tapered seating. The spindle can be clamped when set by a split bush in front, closed by a cam pin B. The anvil is not made adjustable, but wear on its face and on the spindle end is taken up by adjusting the shell or thimble, which, when done, is secured by the taper-headed screw C expanding the end of the micrometer screw into the bushing.

In the Starrett micrometer and some others there is no adjustment of the anvil, but the shell or thimble is adjusted, though held in a different manner from the Bellows.

The Slocomb micrometer is seen in Fig. 389. In this, as in some others, the anvil is fixed, and adjustment for wear is made

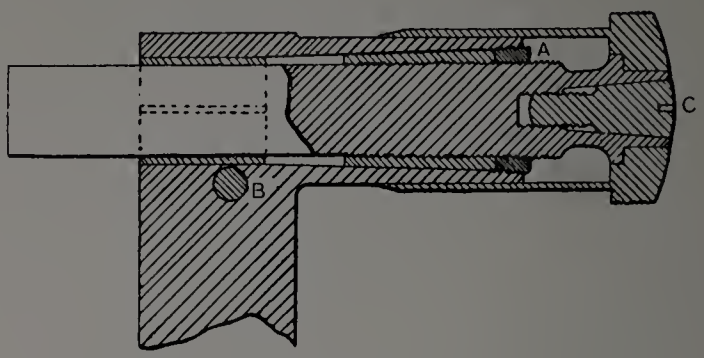


Fig. 388.

at the spindle end. The screw is enclosed at the front end by a bush A, and at the other by the screwed nut B, threaded internally to fit the micrometer screw of 40 P., and externally to fit the barrel or sleeve with another pitch, 32 P. The reason for this is to permit of readjustment for wear, since by turning the nut B the

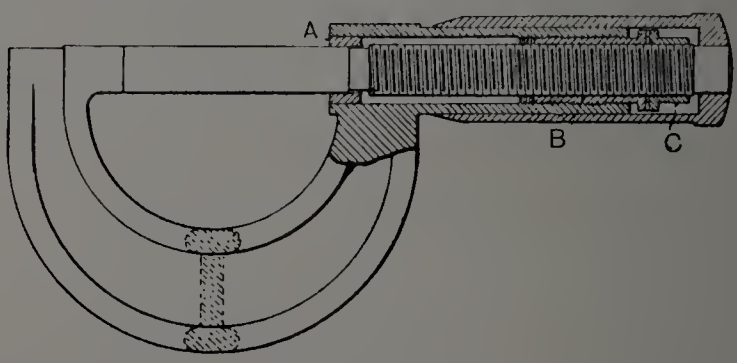


Fig. 389.

spindle will be advanced by the difference in the two pitches. As the difference in an entire turn is six quarter-thousandths, the adjustment is a fine one. The nut B is solid, which is claimed as an advantage over split nuts, as there is no possibility of dirt getting through to the screw, which may happen in split nuts.

The nut C is used for adjustment, which it effects by endlong movement only, so bringing opposite sides of the threads in each

nut into contact with the micrometer threads. The take-up is not effected by frictional contact alone, but by fine clutch teeth and a coiled spring. There are fifty-six V-shaped teeth milled upon the face of each nut B and C to engage with each other. To take up

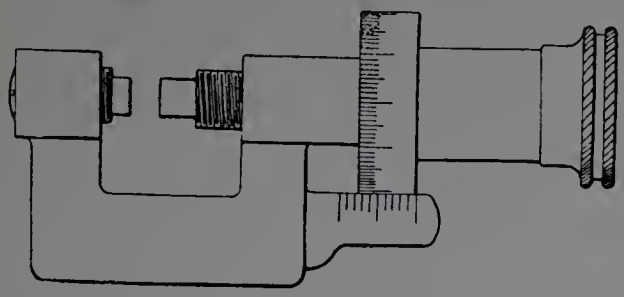


Fig. 390.

slack, the micrometer screw is turned out of the nut B, and then C is turned one or more teeth ahead. An even tension is maintained between the two by a very fine coiled spring occupying a recess between the two nuts.

Fig. 390 represents a German micrometer reading to hundredths of a millimetre. The objection to this type is that the screw is exposed instead of being enclosed and protected as in all the best articles.

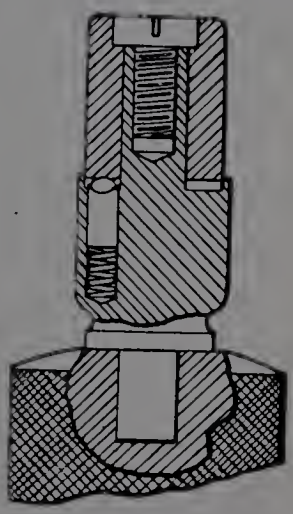


Fig. 391.

As it is easy to vary the amount of pressure exercised on so delicate an instrument as the micrometer caliper, and thus obtain slightly different readings in taking a number of measurements of similar articles, the ratchet stop by the Brown & Sharpe Company is devised, Fig. 391. It comprises a ratchet and spring pawl in the end of the stop, which forms the end of the thimble. The exercise of pressure greater than that at which the instrument is set causes the ratchet to slip past the pawl and stop the further turning of the measuring spindle. In opening the tool, the pawl catches the ratchet, and so prevents slip, and makes the ratchet stop positive in its return. A ratchet stop is also fitted to the Starrett micrometers.

It is usual to stamp on calipers the decimal equivalents of one-

eighths, one-sixteenths, and one-thirty-seconds for the purpose of ready conversion. Calipers identical in all respects are made to metric divisions, reading to hundredths of a millimetre.

The micrometer calipers are made in many styles and sizes. The smallest for engineers' use measures less than $\frac{3}{10}$ in., some less than $\frac{1}{2}$ in., large numbers less than 1 in. Large dimensions are provided for, but the standard form does not go beyond 2 in. maximum; and then the anvil, instead of being a short piece, generally equals in length the projection of the spindle, in order not to give all the overhang to the latter. A clamp screw is usually fitted to secure the anvil firmly. The Starrett Company make an attachment (Fig. 392), to fit over the anvil end, by which any of their 2 in. micrometers can be converted into a 1 in. micrometer. It is clamped in place with the screw seen to the left.

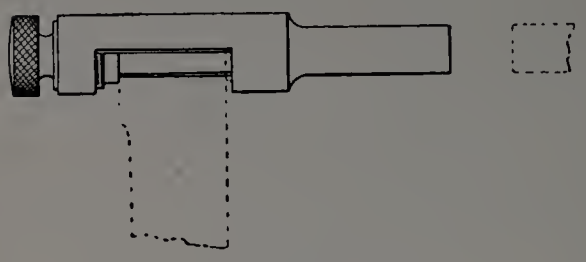


Fig. 392.

When calipers are wanted for dimensions above 2 in., or at most above 3 in., loose measuring points are fitted to lessen the

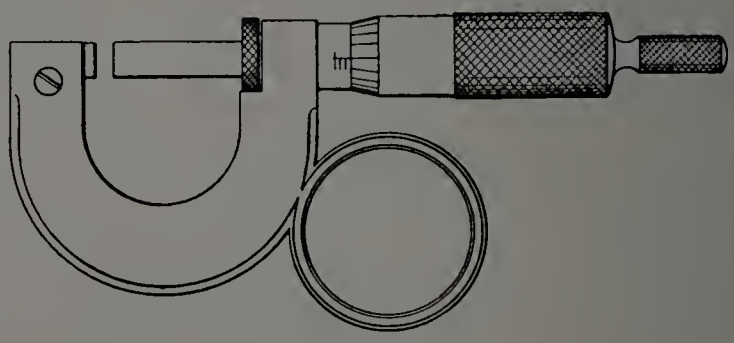


Fig. 393.

overhang of the spindle. Only a limited amount of movement is given to the screws of micrometer calipers, because if about an inch is exceeded, the difficulties of preserving their alignment, &c., are increased. Yet often the limits of such a caliper, bar its range of utility. The alternative is then to have several calipers, or to make one do duty for several by the insertion of loose measuring points.

Calipers are made specially for measuring wire, tubing, sheet metal and paper, and other fabrics. In most instruments the ends of the anvil and the spindle are bevelled off; in a few they are not, but the ends are left parallel in order to permit of measuring up to a shoulder.

A convenience in handling micrometers is a ring (Fig. 393),

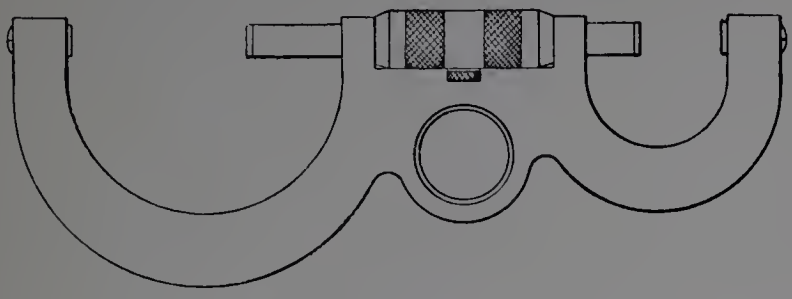


Fig. 394.

provided to slip the second finger into, while the thimble is turned between the forefinger and thumb. In the micrometer by the Massachusetts Tool Company the 1 and 2 in. sizes are combined in one instrument, but without removable points (Fig.

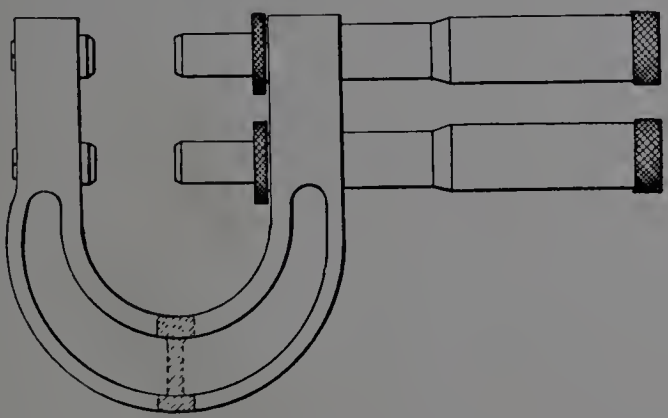


Fig. 395.

394). A finger ring at the centre makes it easy to handle. In this tool the spindles do not rotate as is usual in other makes.

A useful double micrometer is made (Fig. 395), on the same principle as the go-on and not-go-on gauges. The outer micrometer measures the larger size, the inner the smaller.

There is another type of micrometer calipers of large size, of horse-shoe shape, going up to about 12 in. in capacity. Many

variations occur in this design. In the Starrett calipers of this type the micrometer screw has 1 in. of adjustment. One tail spindle or loose measuring point does duty for three separate settings, giving a range with the micrometer of 0 to 4 in. in one size, of 4 to 8 in. in the next, and of 8 to 12 in. in the largest. The spindle is set by means of fine marks ruled 1 in. apart on it, and by which it is clamped in the arm of the caliper.

As temperature would exercise a considerable effect in large calipers, the steel framing is covered with hard fibre, attached with brass screws, which acts as a non-conductor to the heat of the hands.

In the Brown & Sharpe instrument of this type three separate measuring points are fitted, measuring respectively from

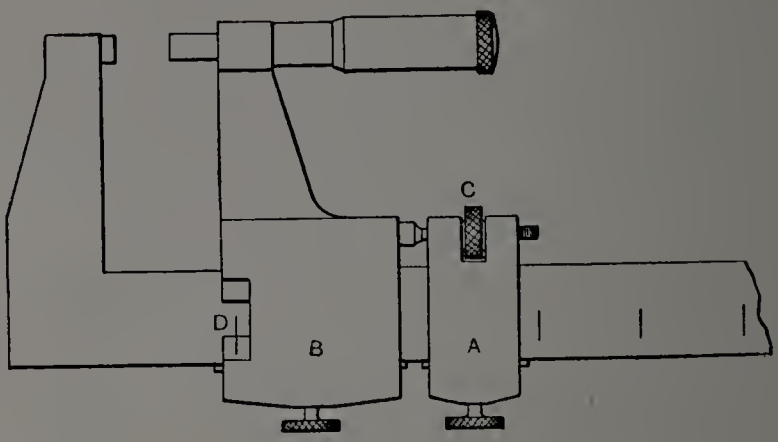


Fig. 396.

3 to 4 in., from 4 to 5 in., and from 5 to 6 in. The entire range covered is from 3 to 6 in. Each point when inserted is secured with a knurled nut, and lock nuts are provided to compensate for wear.

Though most of the micrometer calipers are designed for measuring short lengths only, and generally under 2 in., outside of these there is another type—the beam micrometers, which are used on a similar class of work to the beam vernier calipers. In these, one end is fast at one end, the other movable along the beam, and the latter carries the micrometer. To facilitate the setting of the movable head to each exact inch or half-inch, within the range of the instrument, various devices are adopted.

Fig. 396 illustrates the beam micrometer by the Brown &

Sharpe Manufacturing Company. The method of fine adjustment of the movable head resembles that of the firm's vernier caliper, the block A to the right being clamped with the head in its approximate position, and the head B adjusted by the screw and milled head C. The sliding head is set to inches by lines on the bar, seen to the right, a line D on a chamfered edge on the head

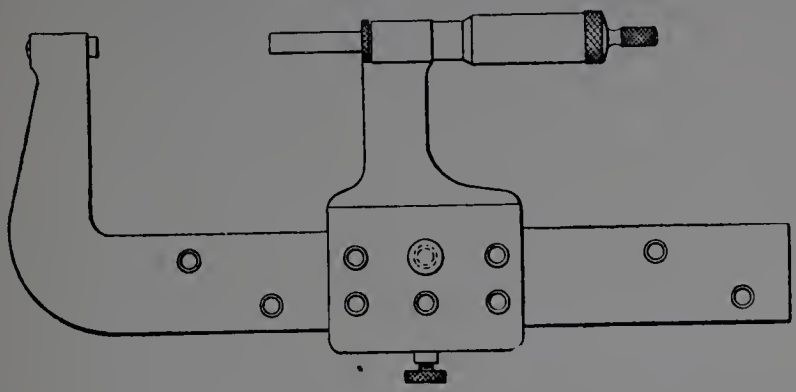


Fig. 397.

being brought to coincide therewith. There can be no wear in such a method as there might be with pins.

In the Starrett beam micrometer (Fig. 397), the movable head is set at each inch, from 1 to 6 in., by inserting a plug through the head and beam. The special feature in this is that instead of using one hole only, there is a separate independent hole for each inch, both in head and beam, so that the wear is divided between all, and wear in one hole would not affect the truth of any of the rest. If one hole only were used in the head, then any want of truth in that hole would impair the accuracy of all the settings. It is, moreover, easier to construct the caliper, as each hole is lapped out to suit its own setting, and no regard need be paid to anything else. All the holes are bushed with steel, hardened, and lapped to fit the plug.

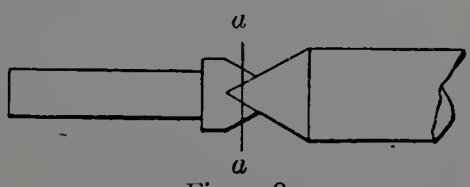


Fig. 398.

In the Bellows micrometer steel pins are inserted at intervals of $\frac{1}{2}$ in. in the beam, a hardened steel stop in the head is brought against either of these stops, and when set is held

in position by a locking screw and nut. Afterwards the micrometer dimensions are taken.

A special form of instrument is the screw-thread micrometer caliper, by the use of which the diameters of threads are measured,

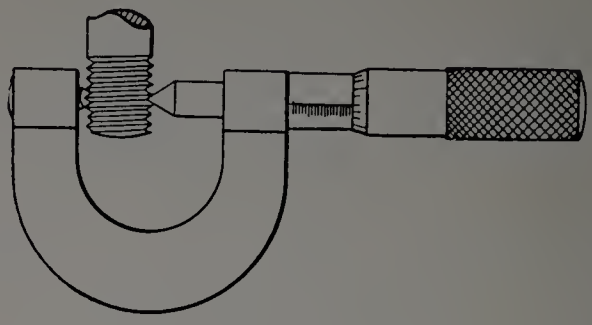


Fig. 399.

not from the outside diameter directly, but from the sides of the threads. The top of a thread may not afford a sufficiently accurate dimension, but the sides should do so. The caliper therefore fits the slope of the threads, and so measures the body; and the dimension obtained is not the normal size of the thread, but the pitch taken at half the depth. The diagram Fig. 398 indicates this. The pitch is equal to the full size of the thread, less the depth of one thread. The micrometer, Fig. 399, is so graduated that when the point and anvil are in contact, as in Fig. 398, the caliper is set at 0. If, therefore, the caliper were opened $\frac{1}{2}$ in., the points *a*, *a* would be just $\frac{1}{2}$ in. apart. As one half the depth of the thread is measured from the top on each side, and as the pitch diameter equals the full size of the thread, less the depth of one thread, the depth is found as follows :—

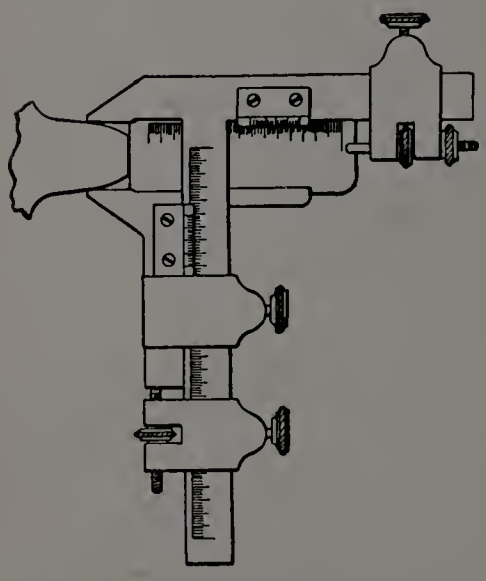


Fig. 400.

Depth of V threads = 0.866 ÷ number of threads to 1 in.
Depth of U.S. standard threads = 0.6495 ÷ number of threads to 1 in.
Depth of Whitworth threads = 0.64 ÷ number of threads to 1 in.

As the U.S. standard thread is flatted $\frac{1}{8}$ of its own depth on top, it follows that the pitch diameter of the thread is increased $\frac{1}{8}$ on each side, equalling $\frac{1}{4}$ of the whole depth; and instead of the constant 0.866, the Brown & Sharpe Company use the constant 0.6495, which is $\frac{3}{4}$ of 0.866. Tables are prepared to facilitate calculation.

Another special caliper is that for measuring gear teeth, their thicknesses, and the depth from point to pitch line (Fig. 400). This is a vernier caliper, having a vernier to both thickness, and depth slides. It reads to thousandths of an inch.

CHAPTER XXV.

Depth Gauges and Rod Gauges.

Measuring Depths, and Diameters—By Rod and Rule—Applications of Micrometer and Vernier to—Forms of Depth Gauges—Reading Dimensions—Refinements in Design—Combination Form—Rod Gauges—Examples.

THE measurement of depths and heights, and that of bores, is generally done in rather a crude fashion, although accurate enough for the work of an average shop.

In measuring depths, the foot rule is used as often as not, the end being thrust down into the hole, and the depth read off on the rule on its edge, or by passing a straight-edge along over the face of the work across the nearest divisions of the rule. Another way is to pass the slide of the slide rule down into the hole, letting the end of the rule rest on the face of the work, the depth to which the slide projects beyond the end of the rule being read off on the slide. If the recess is open on one or more sides, or if its width is too great for the end of the rule to bridge, or if the edges are bevelled or shouldered so that a rule cannot be brought up close to them, a straight-edge is carried across the top face, and a pair of internal calipers tried between its bottom edge and the bottom of the hole, and measurement taken from the calipers. Or depths may be taken by thickness gauges, if such are available.

To take internal dimensions such as diameters, and distances between perpendicular sides, the rod gauge is the common device used in the shops The rule direct is used very often, but it is not possible to make one piece fit another by the rule alone—that is, one could not measure a cylinder bore, and turn a piston, ram, or plunger to fit it, by reference to a rule measurement. If a dimension is started from the end of a rule, that end soon becomes worn and loses its truth. If a dimension is taken from the first inch, there is sure to be some error in setting, as well as in reading off at the other end. For these reasons a rod gauge

is fitted to the cylinder, and a caliper set by that is used for turning the piston or plunger.

The rod gauge is a piece of round steel, from $\frac{1}{8}$ or $\frac{3}{16}$ in. diameter upwards, according to the length, filed at the ends to fit within the diameter, and tapered towards the ends to reduce the area of contact. Measurement is then taken on these narrow areas. The rod gauges are often also retained as permanent records of dimensions, labels being tied on them, giving particulars of the work to which they belong. In taking dimensions with these, they are moved about up and down, and tested across the bore to ensure their fitting at the exact diametral position. This is a very necessary precaution, especially on large bores, where a false fit may easily be assumed to be correct.

These methods, in the light of modern refinements, may appear open to the objection that they are not accurate enough. Yet they are quite precise enough for probably nine-tenths of the volume of work done in any general engineer's shop, and they are not in any degree of the character of makeshifts. In fact, many depth gauges that are manufactured have sliding tongues like those of slide rules, with divisions of the inch on them ; and many internal calipers simply have plain adjustments of the rods, to save filing solid ends to length for every separate dimension.

In high-class tools of these kinds the micrometer principle and the vernier are applied. By means of these, dimensions can be read in thousandths of an inch, or in hundredths of a millimetre, in place of the method of measuring directly with a rule, or with a solid rod. In these instruments the design is that of the calipers —namely, a barrel graduated lengthwise, a thimble divided around its hub, and a measuring point or points. Besides this we have the design of the large calipers embodied—namely, ready settings to large dimensions, apart from the micrometric ones, as half-inches, to increase the range of the utility of the tools.

Depth gauges are variously made. They include the common kind in which the readings are direct, as in the rule ; the micrometer gauge, and the vernier gauge.

The common gauge (Fig. 401) comprises a head of roughly triangular outline, the base of which rests on the face of the work, and a narrow rule which is slid down through the head, in which it is clamped with a screw. In this instrument, which is by Brown & Sharpe, the face of the head is bevelled back at A

to facilitate the reading of the rule. In one form of depth gauge the movable stem is a finely threaded pin passing through a half-nut in the stock. Coarse adjustment can be effected by turning a milled head, which releases the half-nut and permits of rapid sliding of the pin up or down. On throwing in the half-nut, the fine thread affords the means of adjustment. In these—of which there are a good many made—no dimensions are marked. The same remark applies to another type in which a plain round sliding pin is used. In these cases the depth to which the pin projects has to be measured off. These are useful for a large range of work, in which the rule, or slide rule would be too clumsy. It includes a good deal of that done by die sinkers, of work done in lathe and drilling machine, and by bench fitters. They are very cheap, and exceedingly handy instruments.

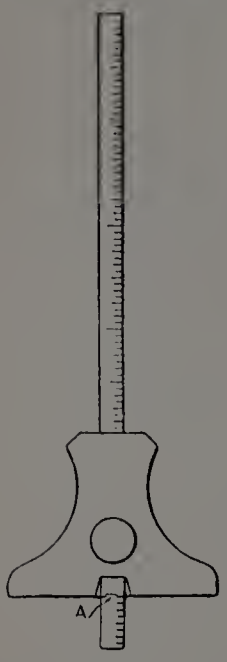


Fig. 401.

Fig. 402.

In others the small round sliding gauge rod is retained, but provision is made for reading dimensions on the tool. In the Sawyer depth gauge the rod is of circular section, fitting in two grooves in one face of the stock—one on each side of the clamping screw. The two grooves have each 1 in. of length finely graduated into 64ths and 100ths respectively. The bar is divided into half-inches only, which gives full readings, while the fine scales give the fractions of inches.

The Brown & Sharpe micrometer depth gauge (Fig. 402) measures all depths and heights under $2\frac{1}{2}$ in. by thousandths. The screw has a movement of $\frac{1}{2}$ in. only, and all equal half-inches are therefore adjusted by a series of angular grooves in the rod A, situated at distances of $\frac{1}{2}$ in. apart, into which clamping fingers at the end of the thimble are sprung, so making each whole $\frac{1}{2}$ in. adjustments quickly. The same design is made to measure

to 60 millimetres in length, and to subdivide to hundredths of a millimetre.

A sectional view of a typical depth gauge, with micrometer adjustment, is shown in Fig. 403—the Slocomb. It is a combination tool, being adaptable for use as a rod gauge. The micrometer section is at A. The body screws on the foot B when used as a depth gauge. For use as a rod gauge, the foot is unscrewed, and a hardened contact-piece inserted instead. The rods are graduated in quarter inches, and the micrometer reads to thousandths.

The Brown & Sharpe vernier depth gauge (Fig. 404) has a

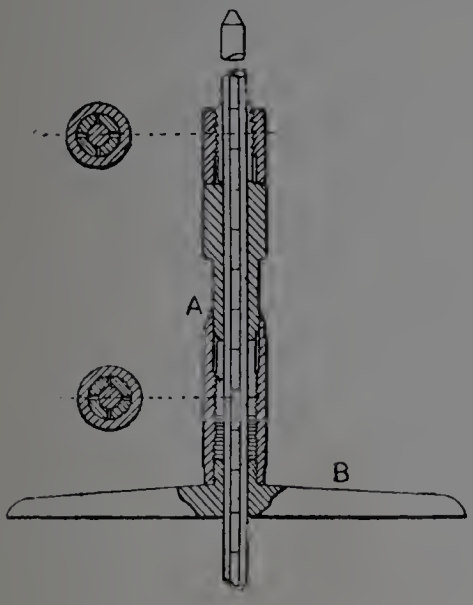


Fig. 403.

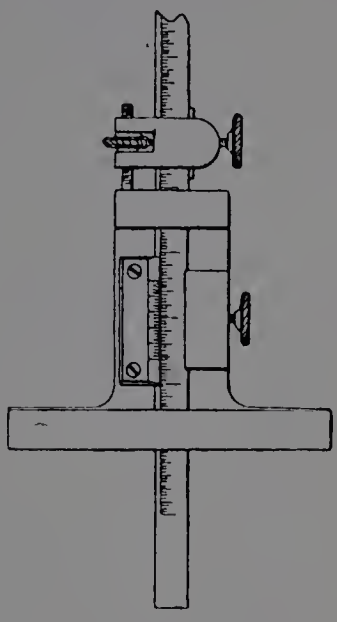


Fig. 404.

head of tee shape, which is movable on the rule in the same way as the vernier caliper made by the firm. The fine adjustment of the head is effected by the second head above, clamped on the rule or beam, and having a fine milled-headed screw for the vernier movements. It reads to thousandths of an inch on one side, and to sixty-fourths on the back, and takes a maximum length of $3\frac{1}{2}$ in.

Fig. 405 is a German vernier depth gauge, without the provision for fine adjustment of the last example.

The vernier is applied to a tool that fulfils some of the functions of a scribing block. The height gauge (Fig. 406), as it is called by the Brown & Sharpe Company, comprises a base about

1 in. wide, to afford a steady support, and forms a fixed end or jaw. The movable head is adjusted finely from another head

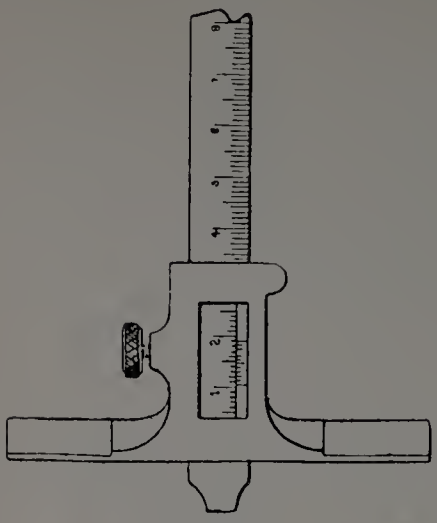


Fig. 405.

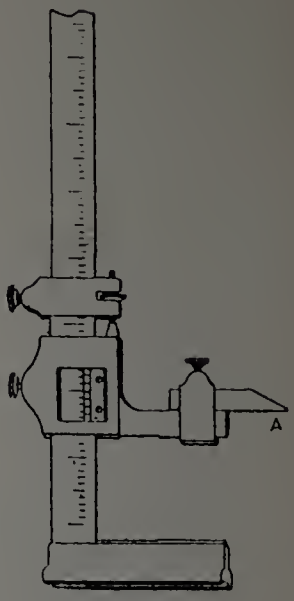


Fig. 406.

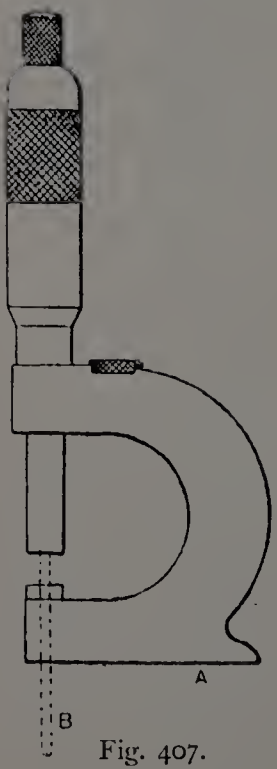


Fig. 407.

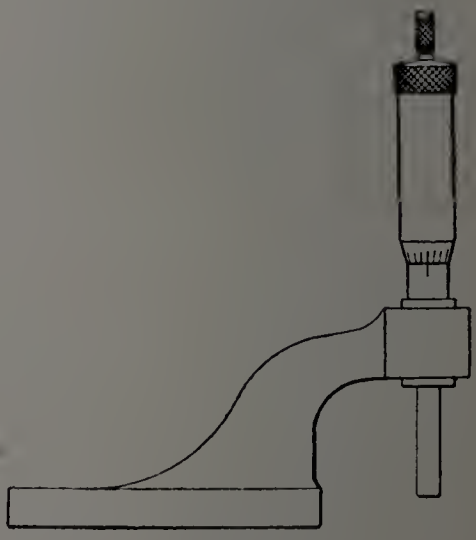


Fig. 408.

clamped to the bar, just as in the vernier calipers. An extension A fits to the movable jaw by a sliding head and clamp screw, by

means of which it can be brought out to varying distances from the jaw. Its face is hardened, and the outer end is ground to a sharp edge. It is thus used for locating centres, scribing lines, or checking the heights of faces that lie beyond the end of the base. The instrument admits 8 in. in height, and reads to thousandths. It is valuable when work is being set and tooled on machine tables.

Another combination tool, shown in Fig. 407, is by the Massachusetts Tool Company, in which a depth gauge is combined with a micrometer caliper. The anvil end A of the caliper is trued. The steel plug B is inserted through the anvil. For depth reading, a second row of figures is stamped on the divisions on the barrel. The divisions on the thimble serve both for the caliper and the depth readings.

A form of micrometer depth gauge is shown in Fig. 408, by which the height of a surface can be checked from a plane surface or from two levels. The difference is given in hundredths of a

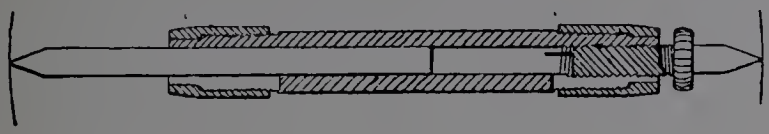


Fig. 409.

millimetre between two levels. To take up wear, the tool is placed on a level plane and the barrel adjusted to zero when necessary.

Inside rod gauges are of two kinds, plain adjustable, and micrometric.

The Pratt & Whitney Company make an inside gauge of the first kind, of simple construction (Fig. 409). A tube carries a chuck at each end, and these are tightened round the split ends of the tube and around the measuring rods. One of these rods is a long smooth wire; the other is a short screwed piece, fitting into a tapped hole in the tube. The smooth wire affords a rough and rapid adjustment, after which the screwed wire permits of a fine adjustment being made. Range in diameters from small to large is effected by changing the smooth wires, three of which are furnished with each gauge. This type is embodied in several other gauges—that is, there is a plain rod clamped in a chuck for coarse setting, and a screwed end or anvil for fine adjustments.

Gauges of these kinds are made in various capacities, usually with three rods to interchange in the body, giving lengths ranging from 3 in. in the shortest to $6\frac{3}{4}$ in. in the longest in one size, and from 6 in. in the shortest to 16 in. in the longest in another size. These gauges being adjustable only, and not micrometric, measurement is taken by reference to any convenient standard.

The bodies are knurled, and the ends of the rods, or rather

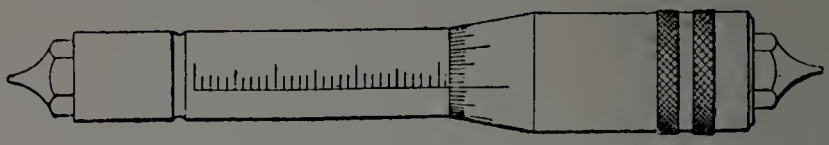


Fig. 410.

wires are hardened. The wires measure about $\frac{1}{8}$ in. only in diameter, and the entire weight is but a few ounces.

In the inside micrometer rod gauge, definite dimensions are read off to thousandths of an inch, or in the metric gauge to one-hundredths of a millimetre. The micrometer screw usually has a movement of $\frac{1}{2}$ in., and extension rods supply the means of increasing the dimensions by half inches. In the Brown & Sharpe, the rods themselves vary from each other by $\frac{1}{2}$ in. In the

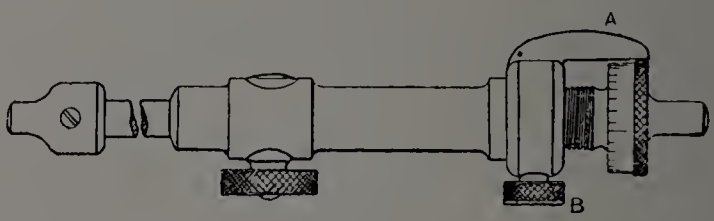


Fig. 411.

Starrett, lines are marked upon the rods at distances of $\frac{1}{2}$ in. asunder. To maintain these lengths intact, each rod in the latter gauge has an adjustable hardened steel anvil in its end. In the former, adjustment is by means of nuts—an adjusting nut and a check nut. The Brown & Sharpe inside micrometric gauge has a screw with a movement of $\frac{1}{2}$ in., and the extension rods, varying by $\frac{1}{2}$ in., enable measurements to be taken from 3 to 6 in.

A rod gauge by Durand & Company in shown in Fig. 410. Fig. 411 is a special form by the Sawyer Tool Company. It has

a large graduated head, over which a steel arm A projects to form the reading point. The reading can be set by the screw B, which locks the micrometer screw by a brass pad. A taper bolt at the other end locks the extension rods, which are of $\frac{1}{4}$ in. steel rod, and the cap shown is slipped over the end and secured with the screw, thus forming a hardened measuring end.

In a French internal gauge, the plain movable point is clamped with a milled-headed screw through lugs on the barrel, which is split at that locality. The micrometer adjustment is at the other end.

Fig. 412.

Woodworkers' gauges can be ranked under two classes, marking and cutting. The first mark lines by which to plane or chisel, the second sever very thin strips of stuff in place of sawing. Both forms have their heads adjustable on the sleeves, and fastened with a wedge, or with a thumb screw. The essential difference lies in the marker, or nicker, or cutter, the first being very fine, the second broader and chisel-like in character. The mortise gauge is a marking gauge, but it stands as a class by itself. Its peculiarity lies in the fact that it has two markers, one fixed, the other movable, with a screw, so that it can be set to any width of

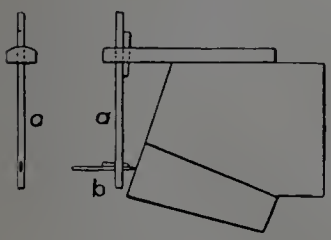


Fig. 413.

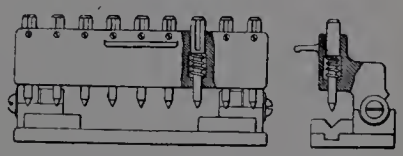


Fig. 414.

mortise required, besides which the head is adjustable. The head is generally faced with slips of brass to present a good wearing surface.

Fig. 412 shows the usual type of woodworkers' gauge, either for marking or cutting, the difference between the two consisting only in the form of the cutting portion.

Fig. 413 shows a shop-made gauge, termed a long-tooth gauge. Both the stem *a*, and the marker *b*, are capable of adjustment, and setting with wedges, to render the gauge adaptable for

marking on surfaces that do not stand at right angles with each other.

Fig. 414 shows a specimen punch, which we class with gauges, because it marks the gauge points on specimen test pieces, so supplying the means of measuring the amounts of elongation at different portions of the pieces.

CHAPTER XXVI.

Snap, Cylindrical, and Limit Gauges.

Horseshoe Calipers—Difference between Standard and Limit Gauges—The Newall System — Provisions against Wear — Accuracy of Cylindrical Gauges—and Horseshoe ditto—Examples of Gauges—Plug and Ring—Snap Gauges.

WE leave now the various calipers and gauges with movable jaws, to consider those in which the jaws are rigidly fixed. These instruments were used when the writer was an apprentice, but they were mostly shop-made articles, and at that time the very high-class fine precision tools, and the system of which they form a part, were practically unknown in English shops. The horseshoe calipers were the forms familiar at that time, and were used for very large as well as for medium dimensions. They were made of a piece of flat bar bent round in the smithy, and filed to the rule, or to another gauge. Though a rough and crude form, they were yet in advance of previous practice, and the working "full" and "bare" to these might be considered as the antecedents of the present-day limit gauges. From those a large family of gauges have descended, but the principle underlying all is the unalterable dimensions of instruments of this class.

Tools of this kind embrace not only the fixed calipers (inside and outside), now termed the "snap gauges," but also cylindrical gauges (internal and external), screw thread gauges (internal and external), and also the limit gauges, and the standard end measure test pieces and rods, as well as the reference discs, which are not for workshop use, but for checking the fixed gauges by. And the price of these articles is regulated by the degree of approach to absolute accuracy which they make.

The difference between a standard gauge, and a limit gauge is a very important one in modern workshop economies. A

standard is one that is practically exact to size, neither being more nor less than the specified size; a limit is one that is both larger, and smaller than the standard by a predetermined amount. In working with a standard, tight fits, and easy fits are made by the discretion of the workman, working full, and bare. In working with limits, the gauge fixes the degree of tight, or easy fits, by the amount of difference between the size of its two ends, predetermined in the manufacture of the gauge. The workman would experience infinite trouble in producing interchangeable work by the first named; the second renders such a task comparatively easy. And not only in fine finishing, but in roughing down work, to be finished by grinding, the latter are invaluable aids.

The modern system has gone far beyond the original one. The plug and ring gauges were, and are, made in two sets, for tight, and easy fits respectively. As a rule, however, in the older practice, the plug was just made to fit the ring, if a film of oil was applied, and the only limits were those which were due to the workman's sense of touch. But practically the departures from exact fits which are required in shops are infinite. A tight fit may be very tight indeed—so tight that it takes the place of keying, or it may be supplemented by keying; a running fit will vary with classes of machines, ranging from the roughest, to the finest instruments of precision. There is, for instance, a wide difference between the fitting of the shafts and bearings of a common winch or crane, or of a mortar mill, or of horse gear, and that of a high-class machine tool of any kind. The value of the modern system of gauging is immensely enhanced by the fact that the exact limits of "tolerance" which are desirable in different classes of work are embodied in the gauges which are designed specially for each class. As such an arrangement would, if carried out to its fullest utilities, demand a large number of gauges, the Newall system has been devised, by which a large number of gradations can be obtained by the adjustments of the gauges, and so the number of instruments is brought within reasonable limits. Standard plugs are employed to set them by, in combination with a graduated dial, and index plate, by which the exact limits required for each class of work are fixed. In these gauges (Fig. 428, p. 315), four classes of fits are taken—force fits, driving fits, push fits, and running fits; and the latter are divided into three groups, so that there are six groups or

classes, besides standard holes, tabulated. In each of these, again, the limits of tolerance vary with the size of holes, being wider as the sizes of holes increase.

The wear of gauges has to be guarded against. In the older shop system ring gauges were readjusted in a rather crude fashion by heating and quenching them, repeating the operation two or three times if necessary. This had the effect of reducing the size of the hole. Horseshoe gauges were set inwards by the hammer. In the case of high-class instruments for fine precision work, it is preferable to make new gauges, the old ones being reground to the next size. The Newall system provides against this by providing what is practically a new gauge for each job.

Cylindrical gauges are made accurately within dimensions ranging from $\frac{1}{10000}$ to $\frac{1}{50000}$ of an inch, with considerable differences in price. The $\frac{1}{10000}$ are sufficiently fine for all ordinary work, the $\frac{1}{50000}$ being used for high classes of work. An illustration of the manner in which gauge making is done is afforded by the statement that a number of lots of cylindrical gauges were "roughed out" to within about $\frac{2}{10000}$ of an inch; eighteen months afterwards a similar lot were roughed out, and the plugs and rings in both sets were found to interchange with each other.

The ring gauges do not give quite the accurate results which may be obtained by fixed calipers of the horseshoe or similar types. The reason probably is that the surfaces in contact are larger in the first case than in the second. This perhaps should make no difference, provided the extent of the contact and the degree of friction were exactly alike in all portions of the circumference and length of the ring gauges. This seems to be paralleled by the difference between wide and narrow pointed calipers, and that between rod gauges with wide and narrow points. Always the finest results are obtained by narrow pointed instruments. And the fact is undoubted that the horseshoe gauges are capable of detecting variations which the ring gauges cannot do. With a 2 in. ring gauge, a variation of $\frac{1}{20000}$ of an inch cannot be detected, while a caliper gauge adjusted to a 2 in. standard cylindrical gauge will show it.

We are dealing, of course, with extremely fine measurements —so fine that they have but a distant relation to the everyday work of the ordinary shop. Yet there are departments of

engineering, and instrument, and watch making in which they find their place. And behind it there is the subject which deals with the methods by which such fine dimensions are obtained. In the work of gauge making a thousandth is too coarse to be dealt with. If a plug gauge one-thousandth of an inch smaller than the ring is inserted, it is a slop fit. In close gauged fits the plug cannot be inserted in the ring without an application of good oil, and if it is allowed to remain stationary for even a few seconds the two will seize and become a driving fit. A man who is accustomed to handling such fine gauges will treat them rather freely without seizing occurring, while one not used to the work will get them seized almost immediately. There is a knack in using them, and a delicate sense of touch, and movement of the wrist which can only be acquired by practice. In standard gauges a margin of but a few ten-thousandths is permissible.

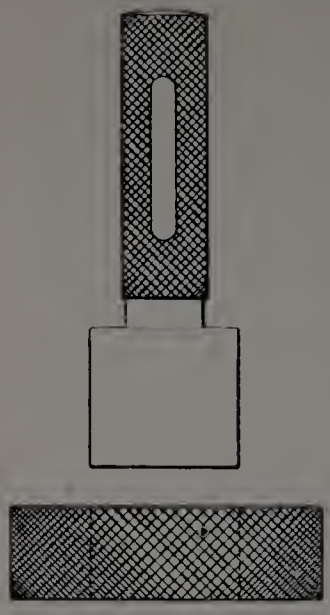


Fig. 415.

Fig. 416.

A few examples of the principal designs in which these are manufactured are given in subsequent illustrations.

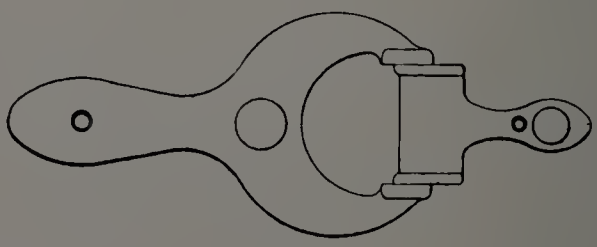


Fig. 417.

Fig. 415 is the plug and ring gauge, differences being made in the form of the handle by different firms. Fig. 416 is the limit plug gauge, with its minus and plus marks, corresponding respectively with the "go in" and "not go in" fits. Generally now the

latter end is made rather shorter than the former, so that the workman can tell at a glance which end he is using.

Fig. 417 represents the Rogers gauges, with handles. These are exact fits—that is, with no limits. The dimensions in which they are made range from $\frac{1}{4}$ in. to 6 in. They are made in two

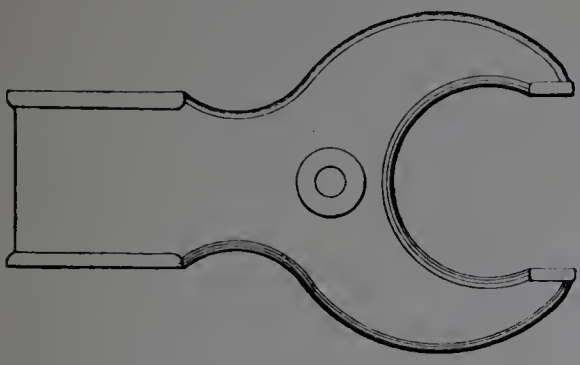


Fig. 418.

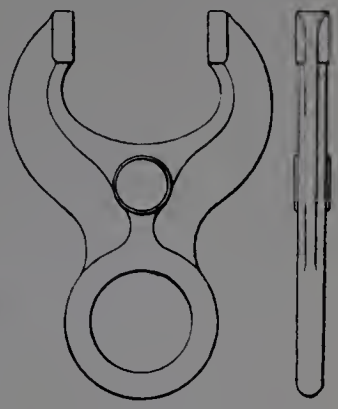
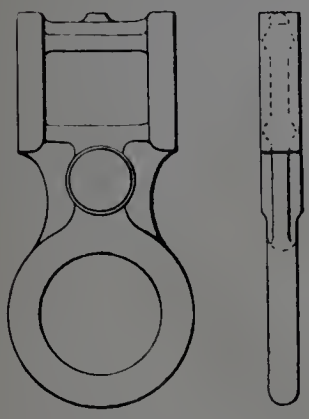


Fig. 419.



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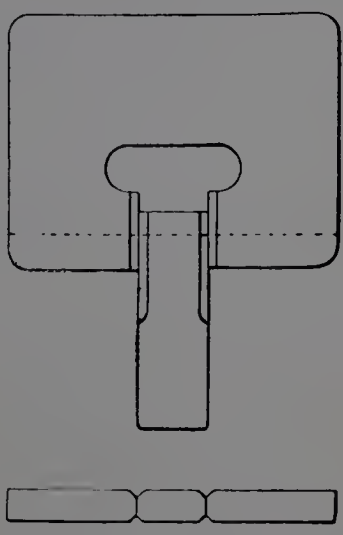


Fig. 421.

classes, one with a limit of error of $\frac{1}{5000}$ in., the other within $\frac{1}{10000}$ in. In another type, the internal and external gauges are combined in one bar (Fig. 418), and made either exact or to limits. Figs. 419 and 420 show some German gauges, made of hardened cast steel, and guaranteed within limits of plus and minus 0.005 mm. Flat, hard steel gauges are illustrated in Fig. 421. The Billings & Spencer drop forged gauge is seen in

Fig. 422. They range from $\frac{1}{4}$ to $2\frac{1}{8}$ in. Two forms of limit gauges by the Rogers Company are shown in Figs. 423 and 424,

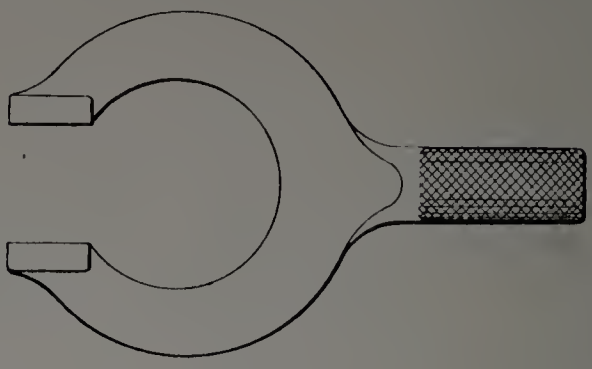


Fig. 422.

the first being the common type, the second containing two sets of dimensions in one gauge, both plus and minus. Fig. 425 is a Brown & Sharpe limit gauge made of plain flat bar.

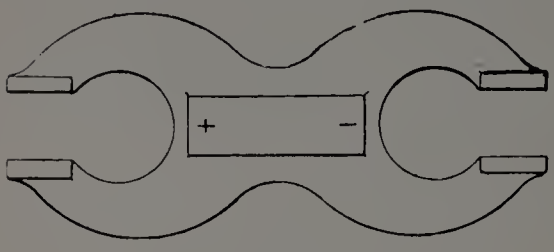
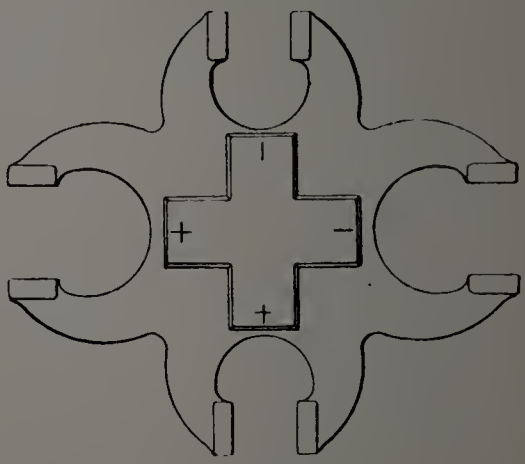


Fig. 423.

Fig. 426 is one of the Loewe snap gauges made from forgings up to 4 in., and above that size in cast iron. The illustration shows how the working faces are formed, being of steel inserted, and pinned in place, hardened and ground, and lapped by hand. A somewhat similar device is shown in Fig. 427, which illustrates the fitting of a hardened steel anvil in a body of forged steel. This is by a French firm. Fig. 428 is one type of the Newall gauge. It has two pairs of measuring points to give the limits, which are adjusted by a series of steel standard bars. When the adjusting screws are set, they are locked by the tightening screws.



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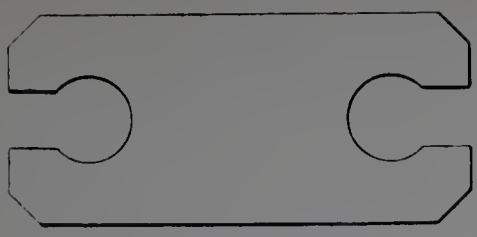

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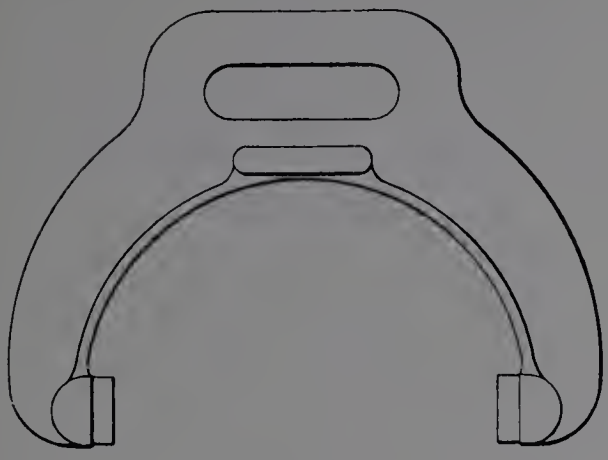

Fig. 426.

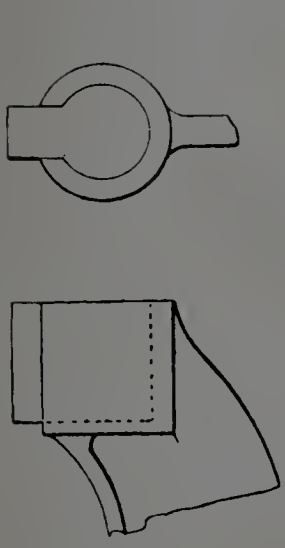

Fig. 427.

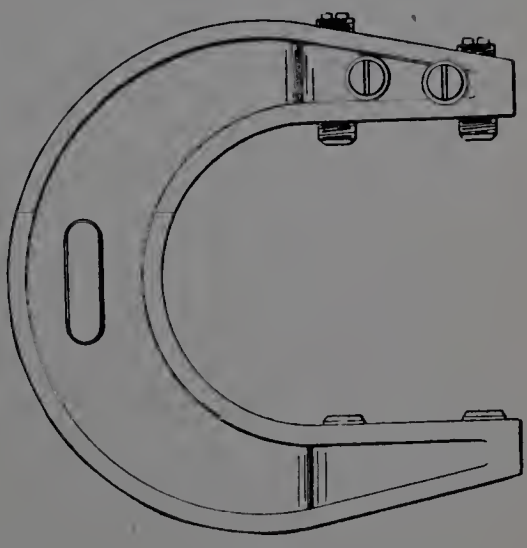

Fig. 428.

The fixed gauges themselves have to be checked as they wear, and so finer gauges are prepared solely to check the working instruments. There are end measure pieces, discs, and stepped

gauges, of which Fig. 429 shows one form. These are generally brought to within about one fifty-thousandth part of an inch of absolute accuracy. Being kept as checks only, wear is practically nil.

Ring gauges may be tested by inserting two or more plug gauges across the diameter, when, if right, they will hold tightly together, just filling up the hole. This is a similar device to that which was adopted by the Pratt & Whitney Company in the manufacture of their gauges. A number of end measuring pieces

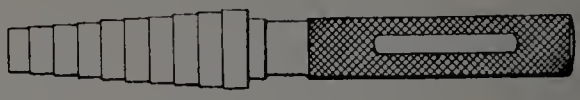

Fig. 429.

were prepared from accurate subdivisions of the yard, and ranging by sixteenths from $\frac{1}{4}$ to 4 in. in length. These were taken at random in numbers sufficient to make up a foot in length, and so made to test each other. A variation of only a thirty-thousandth of an inch in each would have vitiated the results, being a thickness equal to that of the finest gold leaf, which will float in the air. The ends of the standards are so finely polished that they will support each other by their ends, similarly to the best made surface plates.

CHAPTER XXVII.

Screw Thread, Wire, and Reference Gauges.

Gauges for Grinding and Setting Screw Thread Tools—Thread Gauges—Combination Forms—Reference Gauges—Pipe Threads—Gauges for Holes for Screwing, and for Keyways—Wire Gauges.

THERE are a large number of fixed gauges besides those already illustrated, for special purposes, used for angles, screw threads, wire, sheet metals, &c. Those used for screw-cutting form a large class. The following are some of the most common :—

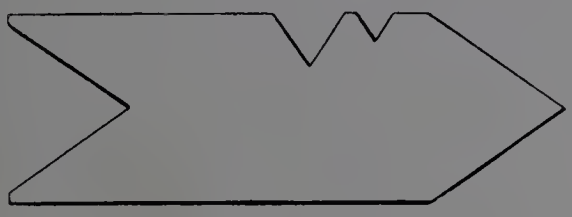

Fig. 430.

The gauge for grinding and setting screw-thread tools (Fig. 430), is made with angles of 60° for United States standard and metric threads, and for lathe centres, and to angles of 55° for Whitworth standard. This little appliance is used for checking the angle to which a tool for cutting screw threads should be ground, and for setting the tool truly both for external and internal threads, and also for testing the truth of threads already cut. It can also be used for grinding flat drills to 60° for centre drilling of lathe work.

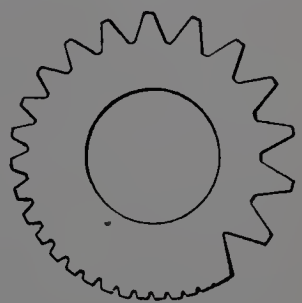

Fig. 431.

A screw thread gauge of circular form is shown in Fig. 431, notched to suit United States standard threads. The single large

V is for grinding the tools, while all the other spaces are formed correctly to the size of thread, so that they may be used for testing the accuracy of the same. The type is also made for Whitworth threads.

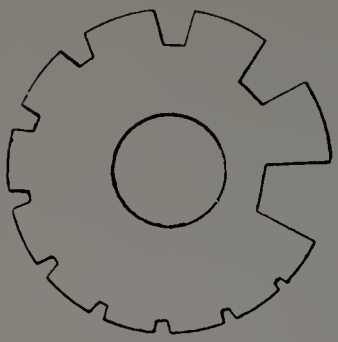

Fig. 432.

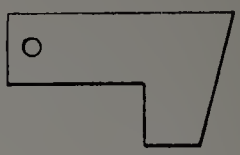

Fig. 433.

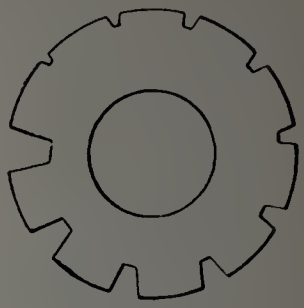

Fig. 434.

Gauges for Acme standard threads, to take the place of square threads, are illustrated in Figs. 432 and 433, and having angles of $14\frac{1}{2}°$, or 29° included angle. The idea is to substitute these for square threads on account of their greater strength, and also to standardise such threads. This, it will be noted, is the same angle as that which is adopted in worm threads for standard involute cutters. Another gauge is used for these (Fig. 434), giving suitable sections for different numbers of threads per inch of the worm.

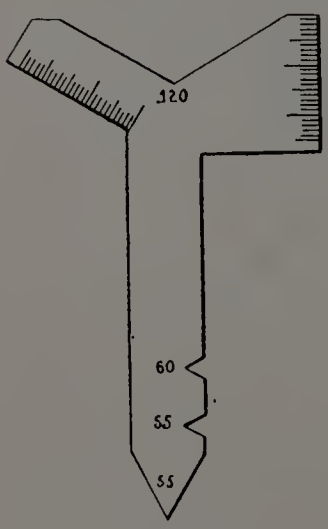

Fig. 435.

A useful form is that with a number of thin pivoted blades at each end of a holder, shut up like a pocket-knife when not in use, and opened out when required. They contain from twenty-two to twenty-six blades, each one being serrated at the edge with several teeth of one pitch of screw. The blades are in some cases made narrow enough to enter into nuts and similar small holes.

The changes are rung on the screw gauges in many other ingenious combinations. One is shown in Fig. 435. It embodies the standard angles for tools for cutting Whitworth, and Sellers threads; two right angles for setting square objects, one being

for internal, the other for external angles; an angle of 120° for testing the lips of twist drills by, the edge being divided into millimetres for checking the length of the lips; an angle of 120° for any six-sided object, as nuts; and an edge divided into millimetres for checking the pitches of screw threads, and generally for taking small measurements.

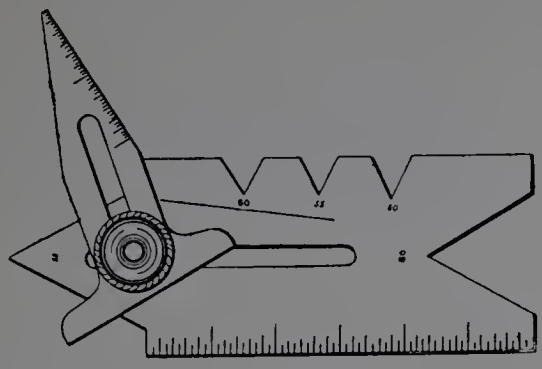

Fig. 436.

A special gauge is Wyke's Universal (Fig. 436). It has, in addition to the standard vees, an adjustable bevel fitted to a slot in the blade, by which its utilities are immensely increased in testing angles and depths, and in setting tools to exact angles. The movable blade can be adjusted in any position and clamped with the knurled nut. The line seen on the face of the main

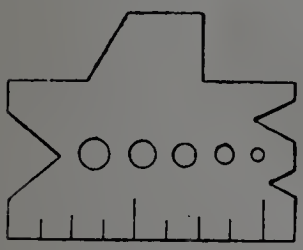

Fig. 437.

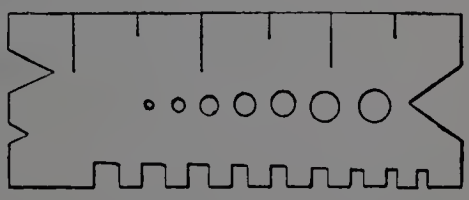

Fig. 438.

stock is to set the bottom edge of the blade by, thereby providing an angle of 120° between the graduated edge of the stock and the undivided edge of the blade. Any other angles can be obtained by the swivelling of the small blade, rendering the tool of wide application, either in machine work or in fitting, to which it is equally adaptable.

Figs. 437 and 438 represent useful combinations. Fig. 437

combines a 2 in. rule divided into sixteenths, thirty-seconds, and sixty-fourths, right angles, an angle of 120° for nuts and drill points, angles for screw cutting, and a few holes for drills. Fig. 438 gives a 3 in. rule finely divided (partly shown in the figure), notches for grinding tools for cutting square threads, angles for vee thread tools, and some drill holes from one-sixteenth to one-fourth of an inch.

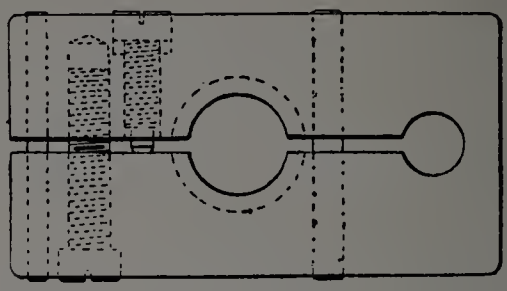

Fig. 439.

Circular screw thread gauges are shown in Figs. 439 and 440. The plug, Fig. 440, has, in addition to the thread, a plain end which gives the size of the tapping hole. The internal gauge, Fig. 439, is split to permit of closing in with wear. One screw forces the halves apart, the other pulls them together. The smooth pins help to prevent lateral spring, which is likely to be caused by the turning of the screws, and which would spoil the

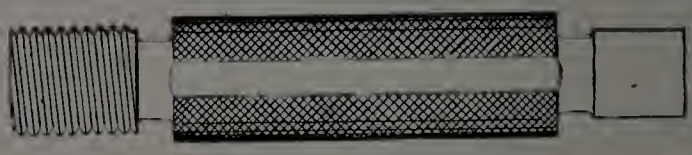

Fig. 440.

accuracy of the gauge. This type is made by the Pratt & Whitney Company in two styles. Both are hardened in the angles of the threads, but one is ground subsequently; the other is not, with of course a considerable difference in price. This gauge represents an advanced stage in construction, since for much work a plain solid gauge is used for testing finished screws, being either in the form of a flat plate with a screw hole in it, or formed as a plug of circular shape. This type of course becomes unreliable through wear, and is at a disadvantage compared with

that in Fig. 439, in which very delicate adjustments can be effected —either closing the gauge in or opening it out. This is useful not only for compensating for wear, but for adjusting to suit a particular fit of thread, either easy or tight. These gauges are used largely in connection with screw machine work for testing the finished products, which must pass the gauge trial or be rejected.

Another group of screw gauges is used for reference only; that

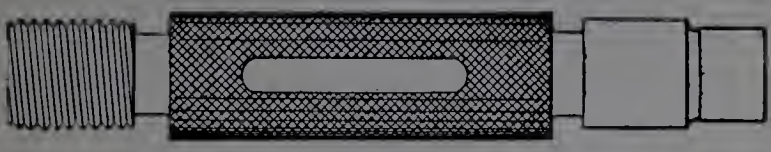

Fig. 441.

is, as standards with which working gauges are compared. These are not hardened, and are not tried directly, but dimensions are taken with calipers and transferred. A single-thread gauge costs the same as a pair of standard gauges which are hardened but not ground.

The Pratt & Whitney Company make a series of gauges for the Briggs United States standard pipe threads, and another set unhardened for reference. The internal gauges in these are

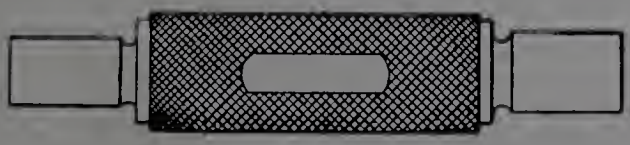

Fig. 442.

plain rings with knurled outsides, the plug solid, with knurled handle.

Many gauges are made as in Fig. 441, the particular example being an Austrian one, having the diameters at top and bottom of the thread at the opposite end to the screw.

Plain gauges are made, as in Fig. 442, for measuring the sizes of bored holes before screwing, two sizes being provided in one body. Another style, either for holes to be screwed or left plain, is shown in Fig. 443, having a number of steps, advancing by small parts of an inch, or of a millimetre. It resembles some standard corrective gauges in form, but is for direct measurement.

The wedge principle is embodied in a gauge for measuring the diameters of holes in nuts and washers (Fig. 444). One edge

Fig. 443.

Fig. 444.

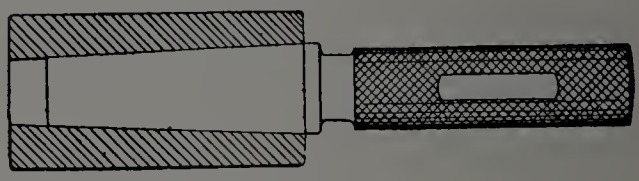

Fig. 445.

reads to 16ths and 32nds, the other to 10ths and 20ths of an inch. As a single gauge of this kind will not cover a large range of holes, a French firm makes a series of five, strung on a ring, the series covering all dimensions from 0 to 50 mm.

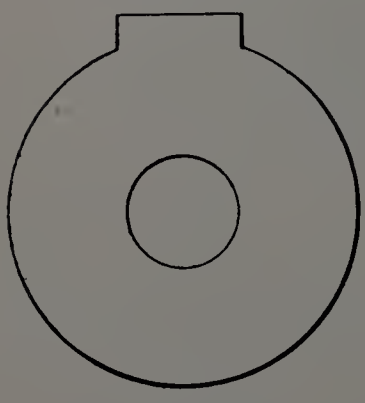

Fig. 446.

Standard tapers have their gauges, both internal and external, as shown in Fig. 445, both being knurled on their outsides.

Keyways are tested with standard gauges of flat sheet form. Fig. 446 shows one for verifying the bore and keyway relatively to each other, the tool being held on a knurled handle, which fits several of the gauges. Fig. 447 gives the width and depth of the key on one side, and the width and depth of the keyway in the shaft on the opposite side, while a smaller piece provides the means of measuring the width of the keyway in the bore. These gauges can be used equally

well for setting the tools to correct widths and depths, and for testing the finished work.

A useful form of gauge, of which we need not say much, is that having holes for standard drills, and holes for tapping drills in combination. These are made in circular and oblong form, and the two sets of holes are also made in separate discs, which

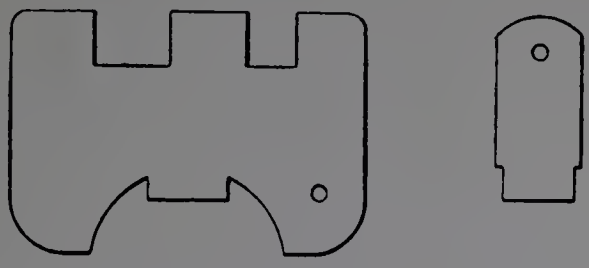

Fig. 447.

are pivoted together so as to fold up and occupy little space. This type of gauge is of more use for setting flat drills, which are forged to shape, than for twist and fluted drills, which are ready provided to standard diameters, and are stamped with their sizes, so that the gauge would be of no use for them, except in the event of the size being defaced, when the gauge is useful to verify the diameter. The size of rod for screwing is also conveniently measured with such gauges.

Fig. 448 shows a twist drill gauge, employed for measuring the angle of the point, indicating whether the same is central, by the divisions, and also for measuring down the shank, thus showing whether the grinding has been done equally.

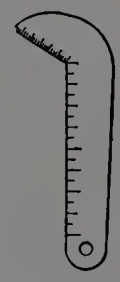

Fig. 448.

Wire gauges occur in numerous designs which are so familiar that it is not necessary to illustrate them. The commonest is the disc, because it happens to be very convenient for putting in the waistcoat pocket. Oblong forms are also commonly used. In each of these the wire is inserted in a slot. In one form, in order to avoid the inconvenience of one large disc, two discs of holes are pivoted together, to be closed over one another when not in service. An elliptical form of this type is also used. Another gauge is the wedge shape (Fig. 449), in which the wire is passed down the angular opening until it comes into contact with both sides, at which place the dimensions or number are read off.

In a combination design, an oblong gauge and a movable caliper are united (Fig. 450). The standard slots are arranged down each of the outer edges of the blade, and a sliding tongue is movable in a recess down the centre, in which it can be clamped. The tongue carries a caliper leg on the blade, and graduations on the edge of the tongue give direct readings of size for odd sizes of stock.

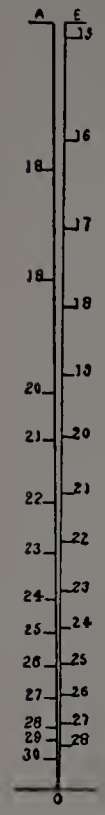

Fig. 449.

The subject of these gauges is still in England involved in much confusion. Many mechanics have endeavoured to evolve some order and standardisation out of the chaos which exists. The result is that the employment of the uncertain B.W.G. still predominates.

There is probably no system of measurement which has been involved in more inextricable confusion than that by means of wire gauges, so that it is necessary when giving large orders, not only to specify the gauge to be used, but also the size in fractions of an inch, or the weight. If the dimensions are given in decimals, these, thanks to the micrometer calipers, are very easily checked, and it also eliminates the errors due to the use of gauges badly worn.

Mr Latimer Clark once gave, by way of illustration of the uncertainty attendant on the use of these gauges, the case of a specification for a contract which he had occasion to prepare, in which the use of either one or other of two gauges would have made a difference of £8,000! The

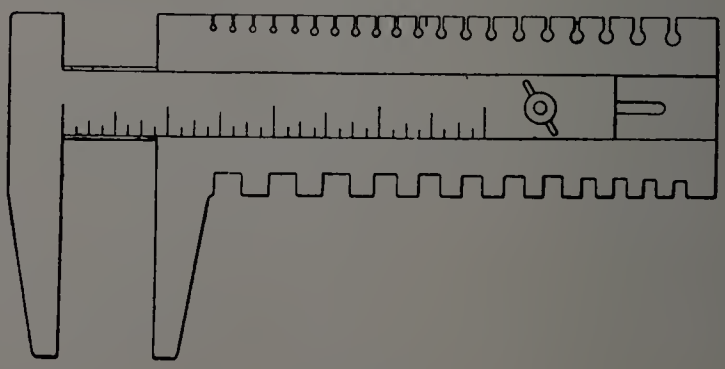
Fig. 450.

B.W.G. is the parent of the others in the sense of priority of age, its origin being lost. A gauge bearing date 1795 is, or

was, recently in existence, while Mr Hughes has shown that the ordinary numbers of wire were in use in 1735, and earlier. It appears to have originated in the requirements of the wire-workers themselves, and to have been constructed in a purely empirical manner. Originally employed for iron wire only, it was called the Birmingham iron-wire gauge; subsequently it has been used indiscriminately for brass, copper, black steel wire, sheet iron and steel, and for screws. Originally its dimensions are thought to have been given in 32nds and 64ths, though now stated in thousandths of an inch, or "mils." Mr Latimer Clark believed the gauge to have originated by calling the largest wire which could be drawn in the days of hand labour No. 1, and the next smaller size which could be drawn at one operation No. 2, and so on; so that the various sizes would be determined by the power of the hand appliances then available for drawing on the one hand, and the cohesive strength of the materials on the other.

In the report made to the Council of the Society of Telegraph Engineers in 1879 it was stated that the different gauges in use could be counted by hundreds; that every wiredrawer had gauges made to suit special objects; that owing to keen competition, wire was drawn by one gauge and sold by another; that half and quarter sizes were sold as whole sizes, workmen being paid by one gauge and the wire sold by another; and that as many as seven different gauges had been made between 20 and 21, and also that the sheet gauges proper were no less unreliable than the wire gauges. A considerable amount of discussion resulted; various new gauges were proposed, based on geometrical principles, and ultimately the Board of Trade sanctioned the "New Imperial Standard Wire Gauge," the highest size of which, 70, is $\frac{1}{2}$ in. in diameter, and the lowest, 50, is $\frac{1}{1000}$ in., or one mil. Even this has not met with general acceptance, for the old B.W.G. holds its own, and will do so probably for a generation or two longer, as do the English measures in the face of the decimal system. The B.W.G. is used in England, Germany, America, Canada, and to a limited extent in Russia and France. As usually made, the numbers in the plate run from 1 to 26, but plates are also made from 1 to 30, 1 to 36, 1 to 40, and 18 to 40. For certain wires—pianoforte, &c.—special gauges are used.

The United States have a standard gauge for sheet and plate

iron and steel, the use of which is compulsory by an Act of the Senate which has been in force since 1893, and no other is permitted to be employed. It embraces thicknesses ranging from $\frac{1}{2}$ to $\frac{1}{160}$ in., denoted by forty-five consecutive numbers. Brown & Sharpe have a wire and sheet-metal gauge, which has been adopted by the brass manufacturers. It gives a grade of sizes which range in geometrical progression, instead of by irregular increments, as does the B.W.G.

CHAPTER XXVIII.

Indicators and Templeting.

Principle of Design—Examples—Relation to the Surface Gauges—Templeting—Templets and Jigs—Their Preparation—Weight—Stamping—Metric System.

INDICATORS are filling a larger place in the workshop than they did formerly. The principle which underlies their design is the magnification of slight errors which, though scarcely visible if measured directly, are rendered very apparent by being magnified at the end of a long lever. Although the principle is simple, many refinements are introduced into different forms. There are two classes, one for lathe work specially, another for testing work during machining and in course of erection.

One of the simplest types, the Brown & Sharpe, Fig. 451, is

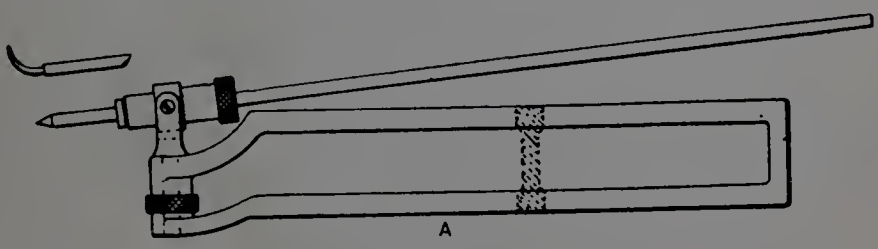

Fig. 451.

fitted by a universal joint to one end of a rectangular bar A, made of a suitable section to be held in the toolpost of a lathe. When a vertical movement only is wanted, the indicator can be clamped so that the bar or finger will only move vertically in its joint. The bushing that holds the finger is split so that the latter can be slid lengthwise. A spiral spring exercises an even pressure on the fingers, two of which are fitted, one with a centre having 60° of angle, the other with a turned-up point.

An indicator of another type by the same firm is shown in Fig.

452. It is used for testing other work besides that done in the lathe, such as in the erecting or testing of machinery. It has a

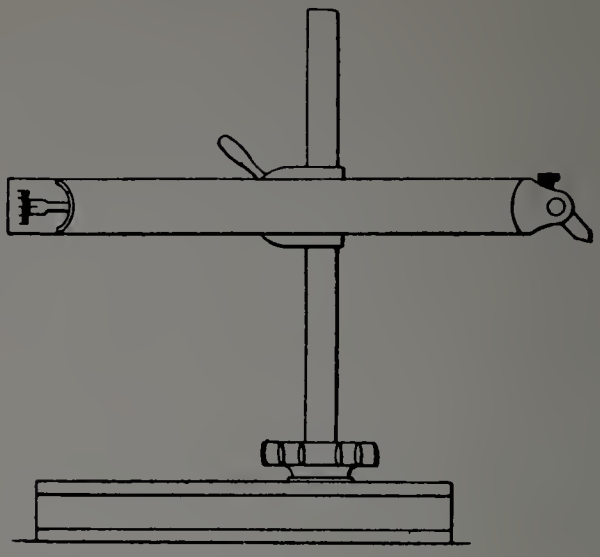

Fig. 452.

base, a post, and an arm, carrying the actual indicating rod. The base is of girder form. The post can be slid along it and

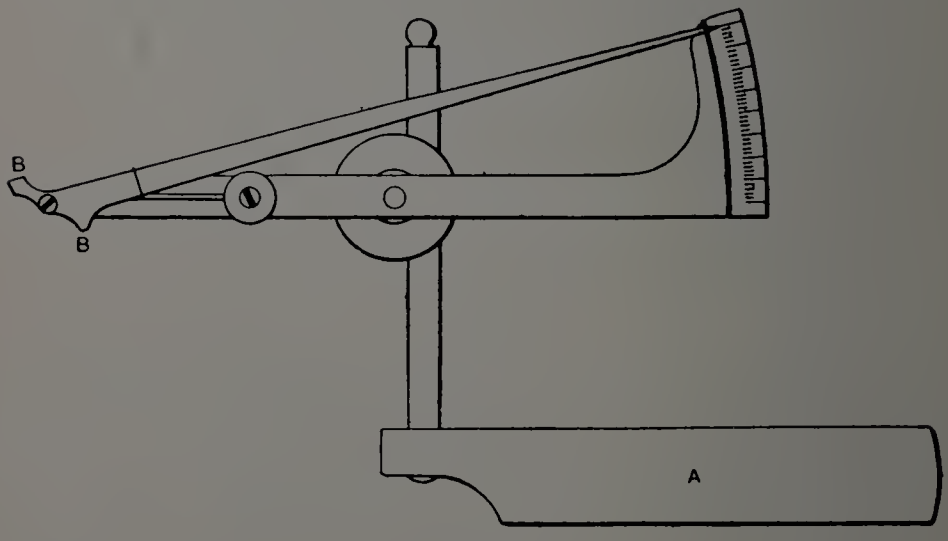

Fig. 453.

clamped in any position by a thumb nut, and the sleeve which carries the arm can be secured at any height on the post. The arm can be turned in its sleeve and set at any vertical angle to

bring the point downwards or upwards, or it can be removed and used apart from the post. An index finger at the opposite end of the pointer moves over graduations of thousandths of an inch, and so multiplies the movements of the point. It can be used in the lathe, as well as on surface work.

The Starrett universal indicator, Fig. 453, is mounted on a heavy base A, which can be clamped in the toolpost of a lathe or

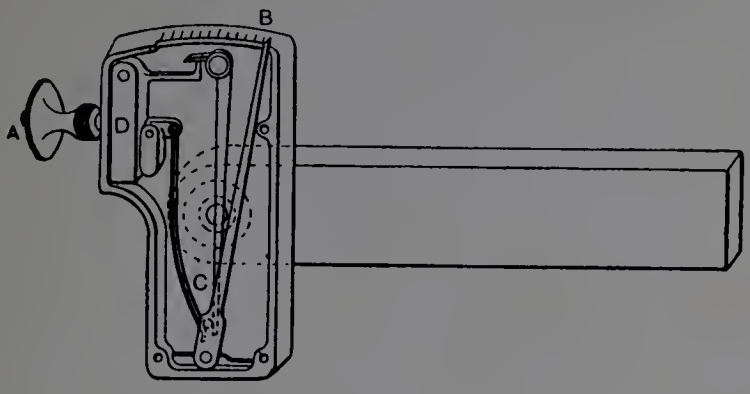

Fig. 454.

elsewhere, or slid along surfaces, in scribing block fashion. It is adapted for face work, or for inside or outside surfaces against which the flats on the head at the extreme left hand B, B in the figure are set. These points are equidistant from the fulcrum. The needle is kept normally at zero by the operation of a spring which has to be reversed when the head is used above and below the work respectively. The change is effected by turning the disc

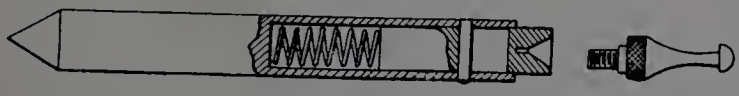

Fig. 455. Fig. 456.

slightly to which the spring is attached. The indicator reads to thousands of an inch. The instrument can be clamped to a support other than the base, as to the needle of a surface gauge.

The Bath indicator, Figs. 454 to 456, is a rather elaborate bit of mechanism, comprising a series of compound levers enclosed in a case (see Fig. 454), by which the movement of the feelers, one of which is seen at A, is multiplied. B is the needle reading over the graduated scale. It is kept normally in its zero position by the

spring C. The feelers are tapped into the hinged block D, four being fitted alternatively to suit various classes of work, the one shown in Fig. 456 being for testing holes. Fig. 455 is a plunger that goes between lathe centres to test the truth of work being chucked by a hole. One end, the pointed one, fits in a hole or centre in the work; the other slips over the poppet centre. One of the feelers is then brought up against the outside of the plunger, and its readings indicate by how much it runs out of truth, and of course the hole in the work also.

There is some resemblance between the surface gauges and the indicators. The important difference is that the first-named do not show by readings how much work is out, while the indicator does. The indicator is used for many purposes for which in average practice the surface gauge has been and is used. It is, for example, employed for levelling work on the planer and during course of erection. It also takes the place of the scriber in testing work on the faceplate and between centres; or, to go into rougher classes of testing, it supersedes the chalk marks put on rotating work to test the amount of eccentricity. It also tests the truth of vertical faces, holding the bar of the instrument in a toolbox or other fixed support, and traversing the face in relation to it. In the hands of some men the indicator is a most valuable instrument for precision measurements. It is especially useful to machine-tool makers. Machines when set up may be tried for their limits of inaccuracy, such as in parallelism of spindles and slides, the indicator giving the most delicate shades of difference, or taper. Readjustments may then be made until the indicator shows that the work is correct.

We conclude the present subject with a brief explanation of the methods of templeting. This system is adopted in order to avoid the necessity of marking out every separate piece of work. A templet being made, every similar piece is marked directly from that, without any aid from measuring instruments. The classes of jobs to which this method is applied are practically illimitable, ranging from those of small dimensions to very big framings. Such templets may include provisions for several sets of operations on one, or on more than one, plane. They serve to line out work for planing and shaping, and for drilling and boring, and they serve to mark angular relations as well as lines on surfaces.

Another class of templets is that to which the term jigs is com-

monly applied. The distinction between the two is that the first-named are used for marking out by; the second are for machining by, without preliminary marking out.

In the first system, measurement cannot be dispensed with for the purpose of checking the work as it proceeds; in the second it is seldom necessary, unless it takes the form of gauging. The difference is that error may arise in working by scribed lines; but when the tools are controlled by a jig, little or no error can creep in, neither can the coercion of the jig be avoided. If the jig is incorrect it must be altered or another made.

Both templets and jigs are made of sheet metals, or castings, the difference depending mainly on what they have to do. Templets for marking out only are generally of sheet metal, filed to the outlines of the work to be marked therefrom, and having any holes required drilled or cut in them. Centre lines are frequently used for setting them by. In other cases, commencement is made from an edge or edges. Templets save a great deal of trouble in the tentative markings-out that are so often employed to ensure that all portions shall hold up for tooling.

In some shops the templet markers work by themselves, doing little or nothing else. In many the fitters make their own templets. The usual plan is to build one machine, or engine, first, and then, taking it apart, prepare the templets of the several portions. This is the safe way. If the attempt is made to prepare templets for sets of work from the drawings, error is almost sure to arise except in the simplest sections, or in those where certain hard-and-fast dimensions must be observed.

The making of most jigs involves more scheming than that of templets. These have acquired a greater prominence in modern shops than they did in the older ones. In the majority of cases they are used for locating the centres of holes, the drills or reamers being controlled by the holes in the jigs. In most cases wear is delayed as long as possible by using bushings for the holes, made of hardened steel. They may be replaced with new ones as they wear badly, without affecting the relative position of the holes. In many instances bushings are essential, as where the main body of the jig is made of sheet metal, and the bushings are required thicker than this. But when the frame of the jig is of cast iron, hardened steel bushes are essential, otherwise the holes in the cast iron would wear rapidly by the friction of the body of the drill.

An important matter to consider is the lessening of weight in templets and jigs. Thus, though those of small dimensions are frequently made in cast iron, large ones are properly plated, often being built up of several strips united with light angles. A solid sheet of metal is not necessary or desirable in large templets and jigs. The only essential parts are the working portions, and it is sufficient if these are tied together suitably with narrow strips. Though in the case of small holes steel bushings are used, yet in large bearing holes that have to be bored, castings are often bolted or riveted at those places to the sheet metal.

It is necessary to stamp all templets and jigs with full particulars of the job for which they are made, as the order number, the date, and the piece. If more details are wanted they can be tabulated in a book.

In conclusion, in the matter of measurement, as in some other departments of engineering practice, we cannot help observing how the practice of the shops is undergoing change. Old methods survive, and must do so, but they become more deeply invaded by the new. It is not that the fitting of parts is more precise than was possible of old, but that now it is both precise and positive, while the old was exact only. This is the result of the invasion of the gauges. Their two great subdivisions, fixed and micrometric, render the taking and checking of the finest measurements practicable and easy—so easy, in fact, that the gaugers in shops are not skilled hands, but lads and girls. The rivalry of the old and the new is only limited by the extent to which high specialisation will take the place of the general shops.

A related question that has been much discussed recently is the compulsory introduction of the metric system. Actually we have seen that most of the measuring tools are made to metric measures, as well as to duodecimal. This testifies to the inroad which the former has made in our shops. Neither America nor England has adopted the metric measures, and yet nearly every class of instrument, rules, and gauges that we have described are offered in both systems, either on the same tool or separate ones. And these are not nearly so much for foreign use as for home. German and French firms are quite able to supply their own people, and are practically independent of American and English goods. Machinists therefore would have nothing to lose by the change to the metric system—in fact, they

have to work by it in executing a good many orders. Already, too, in our finest measurements we think decimally, if not in fractions of the metre, in those of the inch. Tenths, hundredths, thousandths, &c., have already practically displaced the sixteenths, sixty-fourths, and the broken vulgar fractions, in good machine work. Now most men have to use two sets of measuring instruments, while under the decimal system one would suffice. Already some leading firms have adopted it, and others will follow, so that long before the system is legalised it will probably be in active use in all the leading works.

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